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Vol. XIII, Part VI

(December 1943)

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ORIGINAL ARTICLES

WHEAT GRAIN—CHANGES IN ITS COMPOSITION

By J. Walter Leather, Ph.D., F.I.C., F.C.S., Formerly Imperial Agricultural Chemist

(Received for publication on 13 October 1943)

(With one text-figure)

(The following paper on wheat grain written by the late Dr J. W. Leather has been found in the records of the Chemical Section of the Imperial Agricultural Research Institute. Dr Leather's intention was to publish it as a Memoir of the Imperial Department of Agriculture in India, but evidently this could not be carried out before his departure on Military duty during the last Great War and subsequent retirement. In view of the originality of thought and work which anticipated modern trend of research in soil and plant chemistry, it is but fitting that the author should be given credit for the pioneering thought and work by publishing the article in the form in which it was written in Dr Leather's own hand over 30 years ago. The paper is illustrated by a photographic copy of a sheet on which seeds of crops discussed were pasted by Dr Leather.—B. Viswa Nath.)

During the last two or three years several papers have been published showing that the composition of wheat is subject to changes which have been referred to effects of soil or manure, or both.

Hall [1904-5] quotes analyses of flour derived from wheat grown on the Rothamsted and Woburn plots, which exhibits differences in the amounts of total nitrogen and gluten, though no very simple relationship between the nature of the manure and the composition of the flour is discernible, and indeed the differences are only small; the crops were, however, harvested in bad weather.

Le Clere [1906] produces evidence of the influence which several factors have been found to exert on the amount of nitrogen in the grain and on the weight of the seed. Durum wheat grown in arid or semi-arid states contained about 2·8 per cent nitrogen against 2·2 in that produced in humid or irrigated states. Similarly Durum wheats which matured in a short growing period (100 days or less) contained about 2·8 per cent nitrogen against 2·45 per cent in those which required 130 to 250 days.

The effect which varying proportions of lime and magnesia in soils have on the quality of wheat and barley is referred to by Voelcker [1907] who has found that as the relative proportions of lime and magnesia in a soil approach nearer and nearer to the ratio 1 : 1 so the wheat grain tends to become more and more glutinous or 'hard', in other words to show more 'strength'.

Some changes in the composition of wheat having been observed in experiments at Pusa, a brief note on them will be of interest.

For the purpose of some pot-culture experiments, my colleague Mr A. Howard very kindly provided me with a few ears of hard-grey Gangajali wheat, which was sown in jars of local soil, some of which were unmanured whilst to others fertilizers were added. When the produce was harvested, the grain was found to vary considerably in appearance; that which had been grown with the aid of some fertilizers having become very starchy in appearance. The effect was quite uniform throughout the series of cultivations and was so striking that it was decided to make a check experiment during the following season (1907-08). In this experiment some of the 'glutinous' seed which had been obtained from unmanured soil, and some of the 'starchy' seed from soil which had been manured with calcium cyanamide and phosphate, were each grown (*a*) without manure and (*b*) with the aid of oil-cake and superphosphate in order to ascertain whether the changes which had occurred in 1906-07 could be reversed. At harvest this was found to have occurred, and the produce has been analysed, in so far as the material sufficed for the purpose.

Before considering the composition of the grain which is set out in the subjoined statement it will be convenient to mention the chief details regarding the cultivations. The soil employed, that of this Institute, is a highly calcareous one containing upwards of 40 per cent $CaCO_3$; like all soils of the Indo-Gangetic alluvium the amount of organic carbon and organic nitrogen are very small; organic carbon=0·4 per cent, and organic nitrogen=0·05 per cent; the amount of phosphate in a readily assimilable condition is unusually small and addition of superphosphate has a marked effect on all crops, but addition of potash manures does not increase the yield. It is an extremely fine soil even for the alluvium, the particles of 75 per cent of it measuring less than 0·05 mm. and 98 per cent less than 0·15 mm., in diameter, and it holds about 25 lb. of water per cubic foot after drainage has ceased at the conclusion of the monsoon. Excepting then for

a deficiency of organic nitrogen and phosphate, it is an unusually fertile soil.

Both the proportion of moisture in the soil and the nature of the nitrogenous fertilizers employed have differed in the several experiments. They are indicated against each specimen in the accompanying statement and it seems certain that the results obtained cannot be referred to any one of these factors in particular. The effect of nitrogenous manure alone is the same whether a nitrate, or calcium cyanamide or oil-cake is employed; and a corresponding remark applies to the proportion of water in the soil.

An examination of the statement shows how the proportion of nitrogen fell, and the starch increased, when grown in soil liberally manured with a nitrogen compound and phosphate, whilst when the phosphate was omitted the reverse effect was produced. Grown without manure the composition of the grain showed but little change.

Passing to the results of the second year's cultures, it is seen that from the seed grown without manure in 1906-07, a grain of higher nitrogen content was obtained without manure, whilst with the aid of oil-cake and superphosphate a grain of low protein and high starch content was produced. Similarly from the 'starchy' grain produced by the aid of manure in 1906-07, a high nitrogenous grain was obtained without manure, and a 'starchy' one with the aid of oil-cake and superphosphate. That is to say, the change in composition was obtained at will. The amount of seed obtained from some of the jars (those without manure or with nitrogen only) was only small and was too small to admit of both the nitrogen and starch being determined.

These results are interesting both because they are some of the most definite on record, and also because they draw attention to the fact, now becoming more generally recognized, that the character of a soil and its treatment may occasion marked changes in the composition of the produce.

The wheats were grown under circumstances somewhat different from those generally obtained in the field, and it is not suggested that the effects of manures would there be so marked as in pot-cultures, but the general importance of the subject can hardly be over-estimated, and illustrates both the advantage of combining chemical investigation with botanical selection, and also the possible effect which the nature of the soil may have on the composition of at least the fruit of plants.

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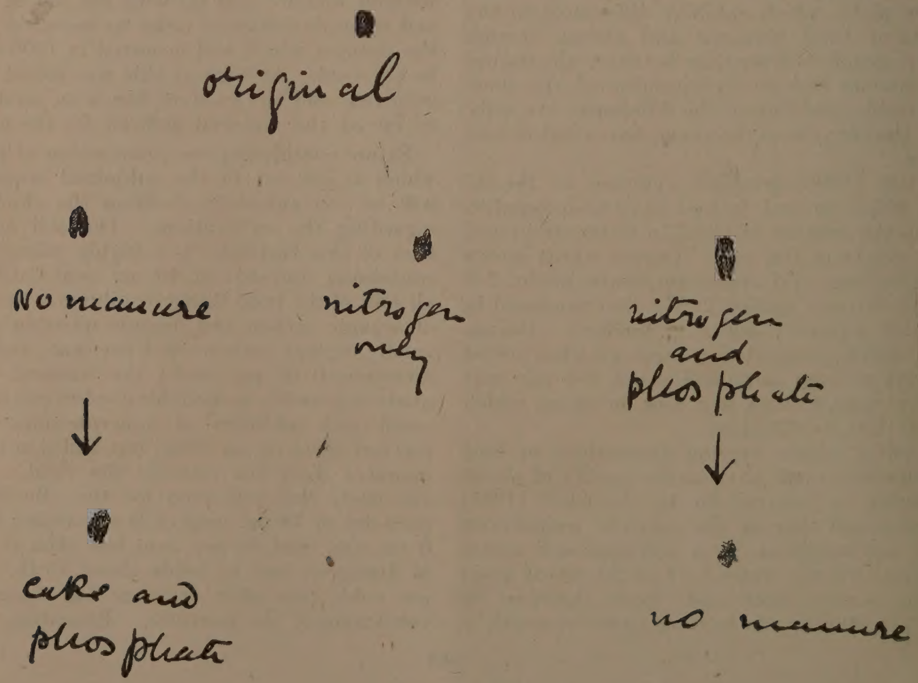

Fig. 1. Seeds of crops

Statement showing the composition of wheat (whole grain)

	Weight of 100 seeds	Nitrogen percentage	Starch percentage
Original seed .	3·5	2·57	50·90

Jar No.	Soil moisture per cent	1906-07 Manure	Nitrogen per cent	Starch per cent	Weight of 100 seeds gm.
101	10	Nil			
401	10	Nil			
105	15	Nil	2·85	49·55	2·5
405	15	Nil			
409	20	Nil	2·46	...	2·9
102	10	Calcium nitrate			
402	10	Cal. cyanamide .	4·44	40·59	2·1
106	15	Calcium nitrate .	(4·445)		
406	15	Calcium cyanamide			
403	10	Cal. cyanamide . and superphosphate	1·56 (1·53)	56·61	4·3
407	15	Do. .	1·72 (1·69)	58·29	3·9
411	20	Do. .	1·56	...	4·3
404	10	Cal. cyanamide, superphosphate and sulphate of potash	1·87 (1·83)	55·88	3·8
408	15	Do. .	1·71 (1·74)	54·96	4·0
Derivative of 409					
403	20	Nil . .	3·19	...	2·6
404	20	Oilcake and superphosphate	1·54 (1·56)	58·87	3·6
Derivative of 411					
401	20	Nil .	3·26	...	2·3
402	20	Oilcake and superphosphate	1·84 (1·87)	57·10	3·3

Change in the nitrogen and starch contents of grain by manuring

Manures N at 50 mg. per kilo as $Ca(NO_3)_2$; P at 100 mg. per kilo as super.; K at 50 mg. per kilo as K_2SO_4 — in jars of 15 kilos capacity

N was determined by Kjeldahl method; starch by Sullivan's method using malt diastase

Soil	Crop	Treatment	Percentage on dry substance N	Starch
Shillong .	Maize .	Nil	1·98	58·1
Do. .	Do.	N . .	2·52	54·7
Do. .	Do.	N+P . .	1·73	61·6
Do. .	Do.	N+P (duplicate pot)	1·83	61·4
Do. .	Do.	N+P+K .	1·94	60·2
Do. .	Do.	N+P+K . (Duplicate).	1·97	59·1
Akola . .	Maize .	N . .	2·32	55·8
Do. .	Do.	N+P .	1·96	58·2
Do. .	Do.	N+P+K .	1·57	60·7
Palur . .	Maize .	Nil	2·05	56·0
Do. .	Do.	N . .	1·75	58·5
Do. .	Do.	N+P . .	1·96	57·5
Do. .	Do.	N+P+K .	2·06	57·2
Pusa . .	Kodo .	Nil	0·87	51·4
Do. .	Do.	N . . .	1·05	50·1
Do. .	Do.	N+P . .	0·92	50·9
Pusa . .	Marva .	Nil .	1·32	59·3
Do. .	Do.	N . . .	1·96	56·3
Do. .	Do. .	N+P . .	1·23	62·3
Do. .	Do.	N+P . .	1·31	58·8
Pusa . .	Rice .	Nil	1·22	56·4
Do. .	Do.	N . . .	1·63	54·9
Do. .	Do.	N+P . .	1·17	57·5

SOILS OF THE DECCAN CANALS

V. INVESTIGATIONS INTO THE CAUSES OF SOIL DETERIORATION UNDER INTENSIVE SYSTEM OF SUGARCANE GROWING, WITH SPECIAL REFERENCE TO THE CHANGES IN THE PHYSICO-CHEMICAL PROPERTIES OF THE SOIL: SOIL FERTILITY SURVEY ON THE NIRA LEFT BANK AND GODAVARI CANALS

By J. K. Basu, M.Sc. (Cal.), Ph.D. (Lond.), F.N.I., Soil Physicist, Sugarcane Research Scheme for Deccan, Padegaon* and V. D. Tagare, B.Sc., B.Ag. (Bom.), Graduate Assistant

(Received for publication on 22 May 1943)

(With six text-figures)

Since the introduction of canal irrigation in the Bombay-Deccan, sugarcane has occupied the most important place among the crops grown in this tract. The rapid growth of the sugar factories in the province has given further impetus to sugarcane cultivation, and at the present moment the concentration of cane cultivation on the canals has almost reached its limit. Striking improvements in cultural methods coupled with the breeding of superior varieties are bringing forth phenomenal yields, and it has become a matter of the greatest concern for the well-being of the society to know whether this type of intensive agricultural practice is going to conserve the fertility of the land for long. Unfortunately soil deterioration—apart from the question of water logging and salt efflorescence—being a slow process, there is no available means of assesing soil changes under a short period of cropping. It was for this reason thought desirable to undertake a detailed fertility survey of the soils of the older canals where sugarcane has been grown for a number of years. The Nira Left Bank and Godavari Canals afforded excellent opportunity for such studies where soils were brought under irrigation for a fairly long time. In spite of certain inherent difficulties in this kind of survey it will be seen that these investigations have thrown considerable light on the problem, and have indicated in a general way the probable causes of soil deterioration and the lines in which further researches can profitably be pursued. It may be worthwhile pointing out in this connection that the value of this work has further been enhanced by corroboration of some of these results in a series of farm experiments under controlled conditions which are running for the last 10 years in succession. The results of these farm experiments will be dealt with in separate papers. The object of the present study is (*i*) to examine critically the past history of the sugarcane soils with a view to trace the causes of deterioration or otherwise of soils under the cultivators' systems of cane-growing, (*ii*) to study the changes in soil properties under long continued cane cultivation, and (*iii*) to correlate soil properties with soil fertility so as to arrive at an understanding of the significance of the soil factors which contribute to the fertility of sugarcane soils.

Survey technique

For the purpose of collecting information, only reliable and intelligent cultivators were approached who could supply the previous history of their plots for a number of years. It may be explained that as the cultivation of of sugarcane requires considerable outlay and incidental expenditure, it has to a large extent assumed the nature of commercialized farming in the Deccan, and even the average farmers in the canal areas are of a more progressive type than those in the less developed areas. The accounts of *gul* produced and manure applied for certain old plots are available with some of the advanced cultivators, and from Irrigation Departmental records it is possible to verify approximately the number of years certain survey numbers have been brought under cane cultivation. Consequently the collection of such information was less difficult than would be expected on ordinary non-cane farms. Attempts were made to get information on the following points:

(*i*) Manurial history,
(*ii*) Yields of sugarcane or *gul*,
(*iii*) System of rotations practised,
(*iv*) Cultural operations usually followed,
(*v*) Approximate quantity of irrigation water applied,
(*vi*) Nature of drainage and other subsoil conditions,
(*vii*) Typical weeds, and
(*viii*) Other informations if any.

The soils were then grouped into two classes, deteriorating and non-deteriorating, the criterion being the calculated quantity of nitrogen

*This scheme is partly subsidized by the Imperial Council of Agricultural Research

required to produce a 40-ton crop of cane per acre in successive periods.

Surface soil (0-12 in. deep) samples were collected from such representative plots of which the above information was available, samples being made composite of six to ten random samples taken over the entire plot depending upon the shape and size of the plot. In order to compare the effect of irrigation and cane-growing on the soil changes similar soil samples were also collected from a fallow or a dry plot near the cane plot which was never under irrigation and represented as far as possible identical soil and subsoil conditions. Wherever possible soil samples were also collected separately from eight months' blocks where other irrigated crops but cane have been taken previously.

The results of the survey are described below:

(A) Old canal—Nira Left Bank Canal,

(B) Moderately old canals—Godavari Canals,

(C) Soil factors responsible for fertility of surgarcane soils.

Presentation of data

(A) *The Nira Left Bank Canal*

This canal was opened in 1885 but the cane cultivation did not spread much till the year 1892 when the area under cane reached over 1,600 acres, the main crops under irrigation prior to this year being wheat, *jowar*, *bajri* and to a certain extent groundnut. The area under cane, however, began to increase rapidly from this year and rose to a figure of over 4,000 acres by 1894, and by 1903 the acreage under cane was well over 8,000. The Saswad *Malis* who took the land on lease, having no permanent interest in the land began to exploit it to the maximum extent, and in order to raise a bumper crop they began to use very heavily irrigation which soon resulted in extensive soil damage in the form of waterlogging and salt efflorescence. These damaged lands had to be left out of cultivation and new lands acquired until the fully damaged lands formed 22 per cent of the total cultivable area in 1925, and 34 per cent by 1930 on this canal [Inglis and Gokhale, 1934]. In spite of these disasters the acreage under cane rose to near about 14,000 by 1927-28, and cane cultivation became a well-established practice on this canal from this time onwards.

Apart from the above-mentioned damages due to waterlogging and salts there were reasons to believe that certain soils were actually 'losing heart due to intensive cane cultivation, and more and more manures were required to be put in these soils every year to secure their former yields. In the discussions that follow only this type of soil deterioration will be considered.

Behaviour of cane soils. Seventeen cane soils have been selected from various representative places from the whole length of the Nira Left Bank Canal whose complete history is known. From the previous history, it has been possible to classify these soils under two groups from the point of view of fertility: (*a*) soils which are either improving or remaining stationary, i.e. non-deteriorating, and (*b*) soils which are deteriorating. These are shown by arrows in Fig. 1. In this graph the soils have been arranged in order of descending fertility, this being calculated as number of tons of canes produced per 100 lb. of nitrogen. Other information such as soil depth, actual yields of cane and manures applied, and some important soil properties are also shown graphically against the soil numbers. It will be evident that the more fertile soils are not deteriorating with the exception of one soil, e.g. No. 45. It will be also noticed that generally speaking the shallower types of soils fall under group (*a*) whereas the heavier soils fall under (*b*) under the existing systems of irrigation in agriculture.

Generally there are four major factors which affect soil fertility, and are responsible for the deterioration or otherwise of soils. They are—(*i*) quantity of irrigation water, (*ii*) tillage operations, (*iii*) manuring and (iv) crop rotations.

(*i*) Since the quantities of irrigation water are never measured by the cultivators, nothing definite can be said about the quantity of water used in cane cultivation excepting the fact that there is a general tendency among the cultivators of over-irrigating (water being charged on acre basis) rather than under irrigating their plots. The dose of water may work up to 140 to 160 acre-inches in most cases.

(*ii*) The cultural operations for cane are not very dissimilar, the usual practice being three ploughings by iron plough, ridging, weeding, inter-culturing and earthing up. Prior to 1909 wooden ploughs were universally used.

(*iii*) About manuring more definite information is available. General trend in the present-day manuring is to diminish the doses of nitrogen, bulk of the reduction falling on the quantities of farmyard manure used. A striking feature of the change consists in the introduction of sulphate of ammonia during the last decade. With the data available at our disposal it is hardly possible to say any thing definite about the efficacy of this change-over in the manuring. However, there are evidences of a beneficial effect of this mixed manuring (i.e. mixture of inorganic and organic nitrogen) in deep soils.

(*iv*) History regarding crop rotations in these soils is fairly reliable and we shall discuss now the merits of these rotations in different soils. In a shallow (<2 ft. deep), well-drained soil a three-

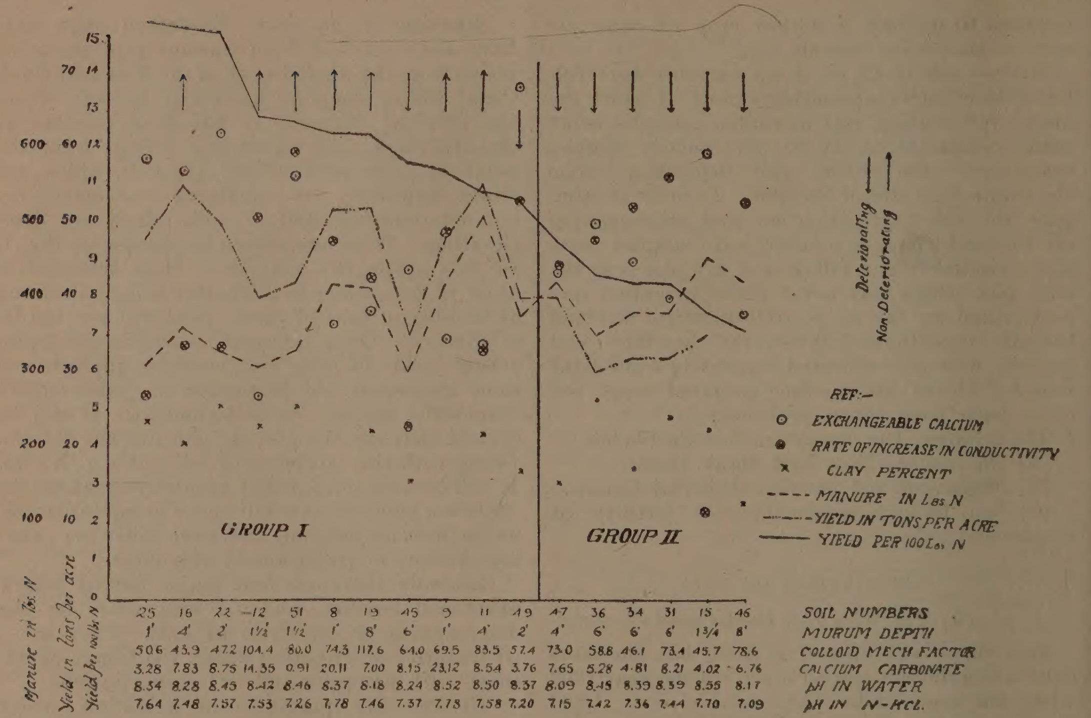

FIG. 1. Soil fertility in relation to physico-chemical properties of soils. N.L.B.C.

year rotation of cane—cotton—*rabi jowar or* cane—rice and gram—*jowar or bajri* (No. 12) has proved successful in improving the fertility of the soil. Even a two-year rotation of cane—*bajri* (Nos. 8 and 9) or cane—$\frac{\text{cotton and gram}}{\text{or wheat}}$ (No. 51) has proved beneficial. Exhausting rotation such as cane ratoon—*bajri* or *jowar* or rice (No. 49) has been found distinctly harmful in the long run. The actual significance of this is shown in Fig. 2. It will be evident that in the rotation cane—rice and gram—*jowar or bajri* the soil gets a rest for 10 months during three years as contrasted with the cane—ratoon—cotton, where only five months' fallow is observed during the same period. If we take cane, ratoon, cotton and rice (because of the impounding water) as exhausting crops we find that under the first rotation the soil is under exhausting crops for only 17½ months as compared with 31 months out of a total of 36 months in the case of the second rotation. From this point of view cane—*bajri* rotation is also much better than cane—ratoon—cotton.

In the case of deep soils (> 4 ft.) all the soils are showing signs of deterioration excepting the soil No. 19 where a four-year rotation of *jowar*—*bajri*—rice—cane has improved the fertility status of the soil. Two-year rotation of cane—cotton or *bajri* or rice (Nos. 45 and 46) has definitely proved harmful while even a three-year rotation of cane—*jowar*—*jowar* (No. 31) has not been able to retain the fertility of a deep soil. Fig. 2 illustrates the advantage of a four-year rotation over a two-year rotation of cane—cotton. There is thus 23½ months of fallow out of 48 months in the first case as compared with five months out of 24 months in the latter case. The periods occupied by the exhausting crops are 17½ out of 48 and 19 out of 24 months respectively. Hence a four-year rotation in heavy soil appears to be quite essential so as to allow sufficient period of rest for recuperation.

Effect of cane growing on soil properties

Some of the characteristic soil properties and the effect of cane growing on these properties are discussed below. These are illustrated in Figs. 1 and 3.

Exchangeable calcium. This property has been determined according to the method of Crowther and Basu [1931]. The proportion of exchange calcium in the colloidal complex determines soil structure and other associated physical properties. A soil which contains a high percentage of this

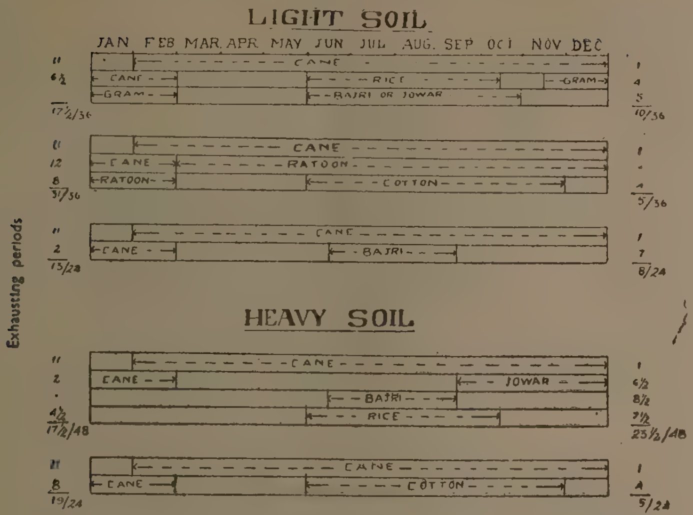

FIG. 2. Effectiveness of different rotations in light and heavy soils (Soil fertility survey)

base is thus most beneficial to crop growth. This is fairly high in most of the soils and reflects in a general way the potential fertility of the soils. It is of particular interest to note that generally the shallower soils (which in majority of cases are non-deteriorating) are richer in calcium colloids than the deeper ones the average figures being 50·86 and 42·41 m.e. per cent respectively.

Generally speaking this soil property is improved as a result of cane-growing. Thus there has been increase in exchange calcium in cane plots over the corresponding plots without cane, in 8 cases, and decrease in 2 out of 14 cases, the increases being more pronounced when comparisons are made between cane plots on the one hand, and the fallow and dry cultivated on the other. The average of 14 pairs shows an increase of about 9 per cent over the control non-cane plots, non-deteriorating soils showing greater increases.

Rate of increase in electrical conductivity of soil solution. Sen and Wright [1931] have shown that the rate of increase in electrical conductivity is an indication of the relative fertility of soils. Our results show that the rate of increase in electrical conductivity is correlated more closely with the amount of manures applied than with the fertility status of different soils as indicated by yields of cane per unit nitrogen. This will be clear from Fig. 1. It is probable that the micro-organic activity is increased by heavy manuring (organic) in cane plots thus causing proportionately increased rate of electrical conductivity. Thus it is likely that this method will prove useful as a measure of the residual effect of heavy manuring in cane soils. In majority of cases (i.e. 10 out of 14) the value has gone up in the cane plots over the control. It is, however, noted that non-deteriorating soils show greater increases than the deteriorating ones, the average increases being 30·91 and 20·07 respectively.

Total soluble salts. Soluble salts present in soils have been determined by conductometric method using L and N Soil Bridge [Davis, 1927]. The values of soluble salts in these cane soils are usually less than 0.5 per cent with the exception of soil No. 45 which has got 0.93 per cent and is showing signs of deterioration. This value has increased in seven cases and diminished in six cases by cane-growing although the average value shows a slight fall. When only the fallow plots are compared with cane plots we find that total salts are lowered by cane-growing in every case.

Soil reaction. This property has been determined by quinhydrone method using Veibel electrode [Biilmann, 1924] and checked occasionally by the colorometric method. The pH in water varies between 8.09 to 8·55 while the NKCl pH gives a range of 7.09 to 7.78. As a result of cane-growing the pH value in water has gone down in eight cases and remained stationary in five cases. Only in one case the value has gone up. pH value in NKCl has gone down only in five cases. The average values in both determinations show a slight lowering.

Calcium carbonate. This is determined by the Scheibler's Calcimeter as described in a previous

publication [1938]. All the soils are well supplied with calcium carbonate with the exception of soil No. 51 which contains less than one per cent. Loss of this soil constituent has taken place by growing cane under canal irrigation in 12 cases out of a total of 14. If the average is worked out over all the pairs of plots it comes to a net loss of about 1.7 per cent or 30 tons per acre foot of soil during the entire period of cane-growing.

Exchangeable sodium. This property has been determined by electrodialysis [Basu, 1931]. The values vary between 0·48 to 1·16 m.e. per cent in irrigated plots while in dry plots values as high as 6.95 m.e. per cent are obtained. It will be interesting to note from Fig. 3 that in the majority of cases (12 out of 14) exchangeable sodium has gone down considerably as a result of cane-growing the average loss being about 70 per cent over the control non-cane plots.

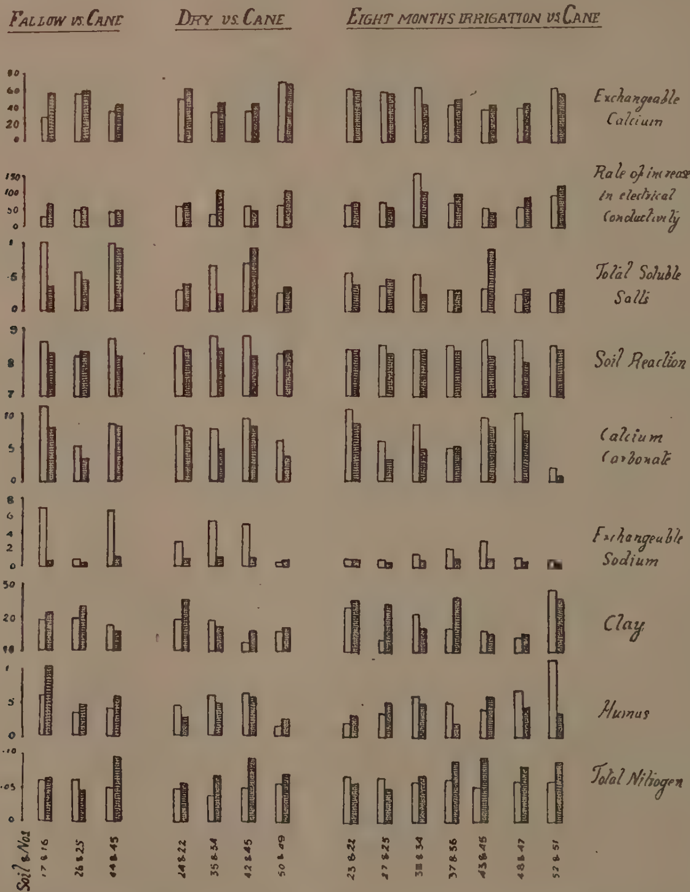

FIG. 3. Effect of irrigation and cane-growing on the physico-chemical properties of soils. N.L.B.C.

Clay and silt. These are determined by the International pipette method [Keen, 1931]. Most of these soils contain round about 20 per cent clay while the silt contents vary widely from 20·6 to 45.0. Increase in clay content has taken place in nine cases there being a fall in the values in five cases due to cane-growing. The average gain in clay during the entire period works out to 1·90 per cent or 34 tons per acre-foot of soil. Similar increases in silt contents of soils are also observed on this canal.

Humus. Determination of this soil constituent has been done according to the method of Sigmond [1927] by extracting the soil with sodium carbonate solution. The values are generally very low in these soils and rarely exceed one per cent. Increases and decreases in humus have taken place in even cases as a result of cane-growing, there being only a slight fall as indicated by the average figure.

Total nitrogen. This has been determined according to the modified method of Bal [1925].

The values range from 0.038 to 0.090 per cent. Generally speaking, nitrogen contents of soils have been increased by cane-growing (10 cases out of 14). The average increase, however, amounts to only 0·016 per cent or about 640 lb. per acre-foot of soil.

Factors responsible for soil deterioration

One of the most important soil properties which control the biological activities in the soils is the carbon/nitrogen ratio of soils. The methods of determination of carbon and nitrogen, and the implications of this ratio on the question of soil fertility have already been discussed in a previous publication [Basu and Vanikar, 1942]. In order to study how these soils, which have been under cane cultivation for a long time, indicate soil deterioration or otherwise when arranged according to the descending order of carbon/nitrogen ratio, 17 cane soils of the Nira Left Bank Canal are graphically represented (Fig. 4) along with other soil properties like nitrogen organic matter, humus and per cent humified matter of these soils. Organic matter (O.M.) was calculated by multiplying organic carbon by 1.724 according to the conventional method [Leather, 1907] and the percentage humified matter obtained by using the formula $\frac{H}{O.M.} \times 100$ where H stands for percentage of humus in soil. The soil deterioration or otherwise is indicated by arrows as usual. It will be noticed from Fig. 4 (A) that soils having carbon : nitrogen ratios higher than 15.0 are all showing signs of deterioration and for values below this, there is a tendency for improvement.

The dotted line shows the nitrogen contents of different soils. Usually, soils having wider ratios show lower nitrogen contents. In Fig. 4(B) the shaded portions represent the humus contents. It will be evident that the deteriorating cane soils show lower humus than the non-deteriorating ones. The total organic matter shows similarly higher average figures for the non-deteriorating when compared with the deteriorating ones. It is also to be noted that the improving soils contain mostly higher percentage of humified matter than the deteriorating soils, the averages being 36.42 and 21.60 per cent respectively.

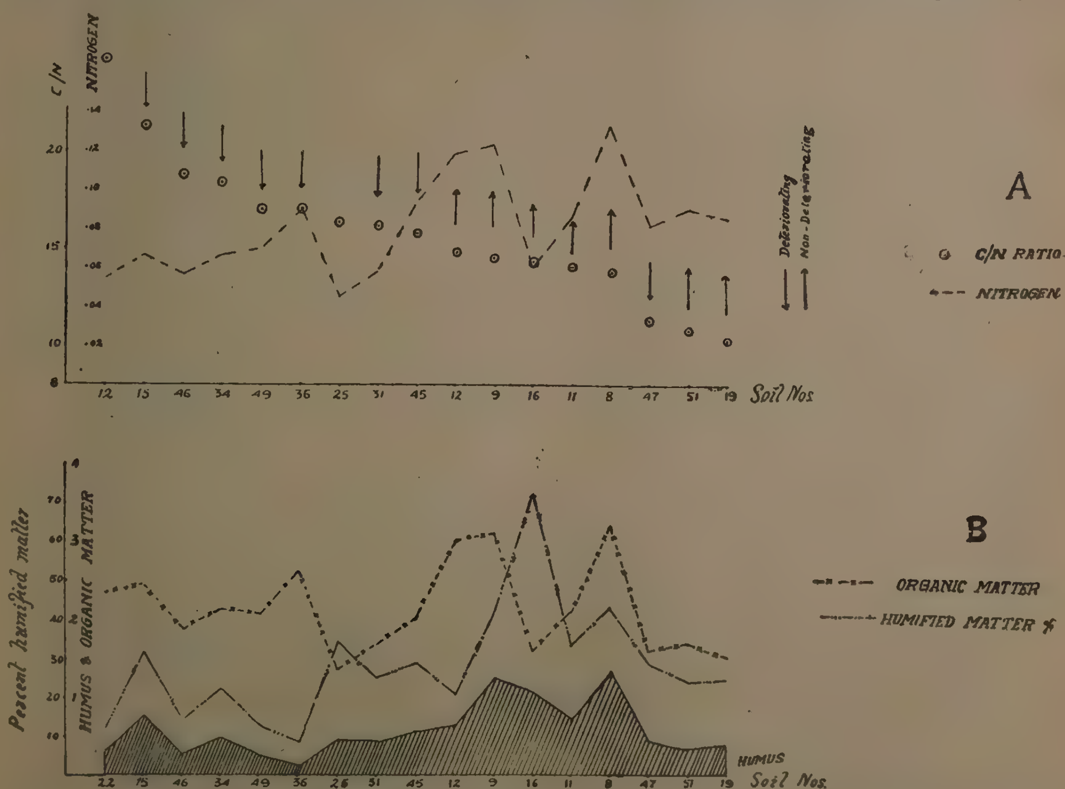

FIG. 4. Soil deterioration as indicated by carbon : nitrogen ratios and other associated soil properties. (N.L.B.C.)

(B) *The Godavari Canals*

Both the Right and Left Bank canals were opened simultaneously in 1911-12, and they soon attracted lot of cultivators especially the cane-growers from the Nira Left Bank canal who were by this time experts in the art of cane-growing. These soils were virgin and undamaged by irrigation, and farmyard manure was available in plenty, and hence these canals flourished, in a very short time, and the cane area rose from 480 acres in 1912 to over 4,000 acres by 1916, and 7,000 acres by 1918. After the last Great War, the prices of *gul* went up very high, and in order to secure very heavy yields, cultivators began to use enormous doses of manure and water. Water-logging and salt efflorescence were the inevitable results. The damaged lands formed 33 per cent of the total area under cane in 1925 and 42 per cent in 1929 [Inglis and Gokahle, 1934]. As a consequence of such wide-spread damage the area under cane began to dwindle down—from an acreage of 9,500 in 1925 it fell to 3,500 by 1931. How the soils behaved under such intensive system of cane cultivation where ratooning is a special feature will be the subject matter of discussion in this section.

Behaviour of cane soils. Twenty-one typical cane soils from the Godavari Right Bank and 29 soils from the Godavari Left Bank were selected for this study. Unlike the Nira Left Bank Canal, these soils had cane only from 4 to 12 years with varying periods of rest (from cane-growing) when dry crops were taken. Hence it afforded us an opportunity of studying soil deterioration under a shorter period of cane-growing. In Fig. 5, the soils are arranged according to descending order of fertility which is calculated from tons of cane produced per 100 lb. nitrogen. Actual tons of cane produced per acre as well as manures in terms of nitrogen are also shown graphically while the soil depth over *murum* are given below the soil numbers. Years under cane and dry crops, are shown by columns against each soil number while the soil deterioration and improvements in the productivity of soils are indicated by arrows. In order to examine these soils

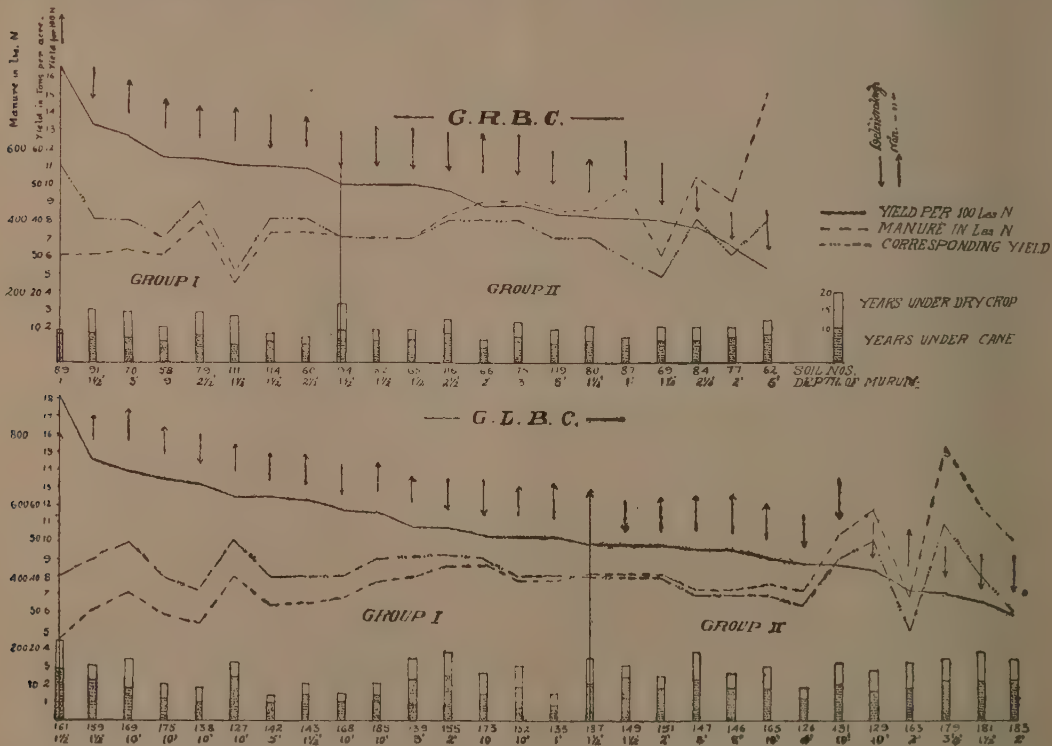

FIG. 5. Fertility status of soils as indicated by cane yields and manuring in terms of nitrogen. (Godavari Canals)

more closely they have been divided into two arbitrary groups—fertile (group I) and less fertile (group II)—by drawing a vertical line at the junction where the curves of actual yield and manure intersect, i.e. soils which produce more than 10 tons of cane per 100 lb. of nitrogen are taken as belonging to the 'fertile' group and others which give 10 or less, as 'less fertile' soils

The most noticeable thing that can be seen from Fig. 5 is that the more fertile soils are deteriorating less than the less fertile soils. Thus on the Godavari Right Bank Canal, we find two out of eight soils in group I deteriorating as against 11 out of 13 in group II. On the Godavari Left Bank Canal there are 4 deteriorating soils out of a total of 15 in group I whereas in group II 8 out of 13 soils are deteriorating. Similar observations were also made in case of the Nira Left Bank Canal. As the exact nature of crop rotations as well as the soils differ considerably on the two canals the discussions on the soil deterioration as affected by crop rotations are given separately below :

On the Godavari Right Bank Canal soils examined were under cane from four to nine years only. It will be apparent from Fig. 5 that soil deterioration is not manifested within four to five years of cane-growing unless the soil is a deep one as in the case of soil No. 119. When we take soils under six years of cane it is noticed that the fertility goes down in most cases where even a four year's rest (from cane-growing) is given, excepting is two cases, i.e. No. 80 and 58, the former being a shallow and the latter a heavy soil. The rotations cane—ratoon—*bajri* and gram—*bajri* adopted for the first and cane—ratoon—*bajri* and gram—*sunn* for the second—seem to be responsible for the maintenance of fertility in the above cases. Cane grown for a period of seven years with rest period up to three years has caused soil deterioration while in soil No. 70 where seven years of rest were given, the fertility has been maintained. With eight years of cane, the same rotation of cane—ratoon—*bajri* and gram—*bajri* seems to be the best (No. 79). Under eight years' cane there is an abnormal case (No. 89) of a shallow soil which has kept up the fertility even under very trying conditions of rotation, namely, cane—3 ratoons—cotton—cane—3 ratoons. But this must be ascribed to the exceptional fertility of the soil—the most fertile of the lot (Fig. 5). There is only one soil with nine years of cane (No. 94) where the rotation cane—ratoon—*bajri*—*bajri* has not been able to retain the productivity of the soil. Evidently, two years of rest from cane-growing are insufficient to maintain the fertility of a shallow soil in the long run where a crop of cane and a ratoon are taken. In the deeper soils (>4 ft.) deterioration starts earlier but no generalization can be drawn from the data of this canal as there are only a few deep soils examined here.

On the Godavari Left Bank Canal, shallow soils show deterioration only after 11 to 12 years of cane-growing while in the case of deep soils, deterioration is found to take place even after five to six years of cane. Unfortunately on this canal no fixed rotation has been followed as in the case of the Right Bank. Among the non-deteriorating shallow soils, there is one soil (No. 187) under 10 years of cane with seven years rest from cane, and three soils (Nos. 161, 163 and 151) under nine years of cane with eight, seven and three years' rest respectively, the behaviour of the last-mentioned soil being exceptional as it had in succession three, two and one ratoon with intervening *bajri* crop. Under 11 and 12 years of cane all soils have shown signs of deterioration but the rest-periods from cane-growing are, however, even less than the periods of cane-growing, and hence it is not possible to say whether the fertility of the soils could have been maintained if sufficient periods of rest were provided. Among the 14 deep soils (>4 ft.) only five soils have deteriorated under varying years of cane-growing (i.e. between 5 and 8 years). It will be interesting to note in this connection that the incidence of soil deterioration among the deeper soils is much less on this canal when compared with those either on the Godavari Right Bank or Nira Left Bank Canal. The presence of a very well-drained soil on the Godavari Left Bank Canal probably accounts for the abovementioned anomaly. It is a deep black clay loam, 5 to 8 ft. deep, overlying a yellowish white alluvial deposit. Thus while cane—ratoon—*bajri*—*bajri* rotation has not been able to retain the fertility of a deep soil (No. 129) even after eight years of cane-growing the same rotation was found to conserve the soil fertility in the case of soil No. 152 which comes under this well-drained soil type. Instances of such abnormal fertility will be seen in soil Nos. 146, 165, 147 and 127.

Effect of cane-growing on soil properties

A comparative statement showing the number of cases where increase, decrease or no change has taken place in the various soil properties as a result of cane growing and the net average change over the pairs of plots (dry and irrigated) in each canal is given in Table I. Further to test to what extent these results are statistically significant, the data for both the banks, i.e. for 48 pairs of soils under varying years of cane-growing (from 4 to 12 years) are analysed for the important soil properties. For analysis of variance, the total of 95 degrees of freedom is split up into its components as under :

Due to (*i*) irrigation . . .	1	Total 95 degrees of freedom
(*ii*) years . . .	8	
(*iii*) interaction of (*i*) and (*ii*)	8	
(*iv*) residual error . .	78	

TABLE I

Effect of cane-growing on soil properties
(Godavari Canals)

Soil properties	Increase or decrease due to cane-growing							
	Godavari Right Bank Canal— Number of cases				Godavari Left Bank Canal— Number of cases			
	+	—	0	Average	+	—	0	Average
Exchangeable calcium	13	7	0	+1·25 m.e. per cent	13	15	0	+1·27 m.e. per cent
Rate of increase in conductity	12	8	0	+4·38 per cent	20	8	0	+20·14 per cent
Total soluble salts	14	5	1	—0·024 per cent	12	15	1	—0·029 per cent
*p*H in water	6	14	0	—0·032	8	18	2	—0·054
*p*H in N. KCl	7	10	3	—0·024	5	19	4	—0·078
Calcium crabonates	4	16	0	—0·92 per cent	12	16	0	—0·51 per cent
Exchangeable sodium	9	8	3	—0·53 m.e. per cent	6	22	0	—0·38 m.e. per cent
Clay	13	5	0	+4·40 per cent	16	7	2	+2·08 per cent
Silt	8	10	0	—0·96 per cent	9	15	1	—0·82 per cent
Humus	8	12	0	—0·07 per cent	8	20	0	—0·10 per cent
Nitrogen	11	7	2	+0·001 per cent	23	4	1	+0·011 per cent
Available phosphate	9	9	2	+0·001 per cent	21	4	3	+0·003 per cent

TABLE II

Effect of cane-growing on soil properties—Statistical significance of 48 pairs of soils (Dry vs. cane)
(Godavari Canals)

Soil properties / Due to	Observed value of *z*			Expected value of *z* for 1 per cnet point			Significance		
	Irrigation	Years	Interaction	Irrigation	Years	Interaction	Irrigation	Years	Interaction
Exchangeable calcium	—0·9144	0·0303	—0·8998	0·9462	0·4604	0·4604	Not significant	Not significant	Not significant
Rate of increase in conductivity	1·3413	0·5705	—0·0445	0·9462	0·4604	0·4604	Highly significant	Highly significant	Do
Total soluble salts	—0·6703	—0·3608	—0·9824	0·9462	0·4604	0·4604	Not significant	Not significant	Do
*p*H in water	—0·1008	0·4876	0·0500	0·9462	0·4604	0·4604	Do	Significant	Do
Calcium carbonate	—0·2923	—0·0029	—1·1933	0·9462	0·4604	0·4604	Do	Not significant	Do
Humus	—0·5809	—0·7154	—1·2454	0·9462	0·4604	0·4604	Do	Do	Do
Nitrogen	0·8482	0·0222	0·7366	0·9462	0·4604	0·4604	Do*	Do	Significant

* Significant for 5 per cent point in the case of irrigation

A summary of these analyses is given in Table II. These results are briefly discussed below.

Exchangeable calcium. On the Right Bank majority of soils have gained in this property under irrigation and cane-growing, whereas on the Left Bank the cases of gain and loss are almost equal. However, the net result is a gain on both the canals of 1.25 and 1.27 m.e. per cent per plot respectively. On referring to Table II, it will be seen that neither irrigation nor years (of cane-growing) has any statistically significant effect on this soil property. Considering the intimate relationship existing between the nature and amount of soil colloids in the soil profiles and the morphology of different soil types [Basu and Sirur, 1938] it is very likely that the effect of irrigation on this particular soil property may be entirely dependent on the genetic characteristics of these soils.

Rate of increase in electrical conductivity. On both the canals, majority of soils have shown an increase in the property due to irrigation, the Right Bank showing an average increase of 4.38 per cent and the Left Bank of 20.14 per cent per plot. Statistically it will be observed that both the effects of irrigation and years are highly

significant. It seems probable that the rate of increase in electrical conductivity is independent of soil types. It has already been referred to in a previous section that the rate of increase is correlated more closely with the amount of manures applied than with the inherent fertility of different soils.

Total soluble salts. On the Right bank more soils have gained in total salts whereas opposite is true for the Left Bank. Magnitudes of these changes being very small, the net result is nil on the Right Bank and a slight lowering on the Left Bank soils. As the changes due to irrigation are practically very little, there is no statistical significance observed in this property.

Soil reaction. Effect of irrigation is to lower the *p*H values and exchange acidity in most cases, but there are certain cases where it has raised the values. Net result, however, is a slight lowering of the values on both the banks. On referring to the statistical table it will be seen that the lowering is only significant in the case of 'number of years' which indicates a slow but definite influence of irrigation on soil reaction.

Calcium carbonate. Losses in calcium carbonate under irrigation are general on both the canals, although there are more erratic values on the Left Bank than on the Right. The net result is a loss in both cases, being 0·92 per cent and 0·51 per cent per plot on the Right and Left Bank respectively. Statistically, however, no significance is obtained.

Exchangeable sodium. This soil constituent has been lowered in the majority of cases on the Left Bank while on the Right Bank number of cases is about equal for both gain and loss. The net result is, however, a general lowering of 0.53 m.e. per cent and 0·38 m.e. per cent respectively for the Right and Left Bank Canals.

Clay and silt. In majority of cases, the percentage of clay has increased on both the canals, the average increases being 4·40 and 2.08 per cent on the Right and Left Banks respectively. Slight decreases in the percentage of silt are, however, noted on these canals, significance of which will be discussed later.

Humus. It will be observed that there is a general tendency of lowering of humus by cane-growing but the average figures indicate a very slight loss on the whole. Analyses of variance also do not show any statistical significance either for the effect or irrigation or number of years under irrigation on the humus contents of soils.

Total nitrogen.—It will be observed that cane-growing has generally increased the nitrogen contents of soils in the case of both the canals. Statistical analysis of these data also indicates that the effect of irrigation is significant for $P=0.05$ whereas for interaction between 'irrigation' and 'number of years' the z value is highly significant (i.e. for $P=0.01$).

Available phosphoric acid. On the Godavari Left Bank Canal the majority of cane soils show higher available phosphoric acid by Truog's method [Wright, 1934] than the non-cane soils while on the Right Bank Canal there is an equal number of soils showing increases and decreases due to cane-growing. However, in both cases there are net gains in available phosphoric acid when the averages are taken of all pairs of plots.

Factors responsible for soil deterioration

In Fig. 6 (A and B) cane soils of the Godavari Right and Left Banks have been shown in order of descending C/N ratio, indicating the deteriorating and non-deteriorating soil by means of arrows. Other relevant soil properties like organic matter, humus, per cent humified matter and nitrogen are also indicated by appropriate lines and shading. Most striking thing to note is the fact that above certain limiting C/N ratio (i.e. above 15.0) all soils are showing signs of deterioration in both the canals. It will be remembered that similar observations were also made in connection with the soils of the older canal—i.e. the Nira Left Bank Canal. Coming to the nitrogen curves, it will be seen that unlike the Nira Left Bank Canal soils, the soils with wider C/N ratios show higher nitrogen contents in these canals. Similarly both organic matter and humus contents are higher in the soils with wider ratio which is not the case in the Nira Left Bank Canal. Explanation of this anomalous behaviour will be given later. So far as the per cent humified matter is concerned, the Godavari Left Bank Canal soils are showing higher values for the non-deteriorating than the deteriorating ones, the average figures being 32.91 per cent for the former as against 24.16 per cent for the latter. In the Right Bank, the deteriorating and non-deteriorating soils show equal average values.

(C) *Fertility of sugar-cane soils*

It is already known that the factors responsible for soil fertility differ according to variations in climate, soil and crop. In order therefore to find out the most important soil properties which are primarily responsible for higher productivity of sugarcane soils in the Bombay-Deccan, 31 typical soil samples were collected from the Nira Left Bank and Godavari Canals where reliable history of manuring and cane yields was available. The following precautions were taken in order to get comparable results of soil analysis :

(*a*) All the soil samples were collected in the month of November, within a fortnight, so that the seasonal variation may be negligible.

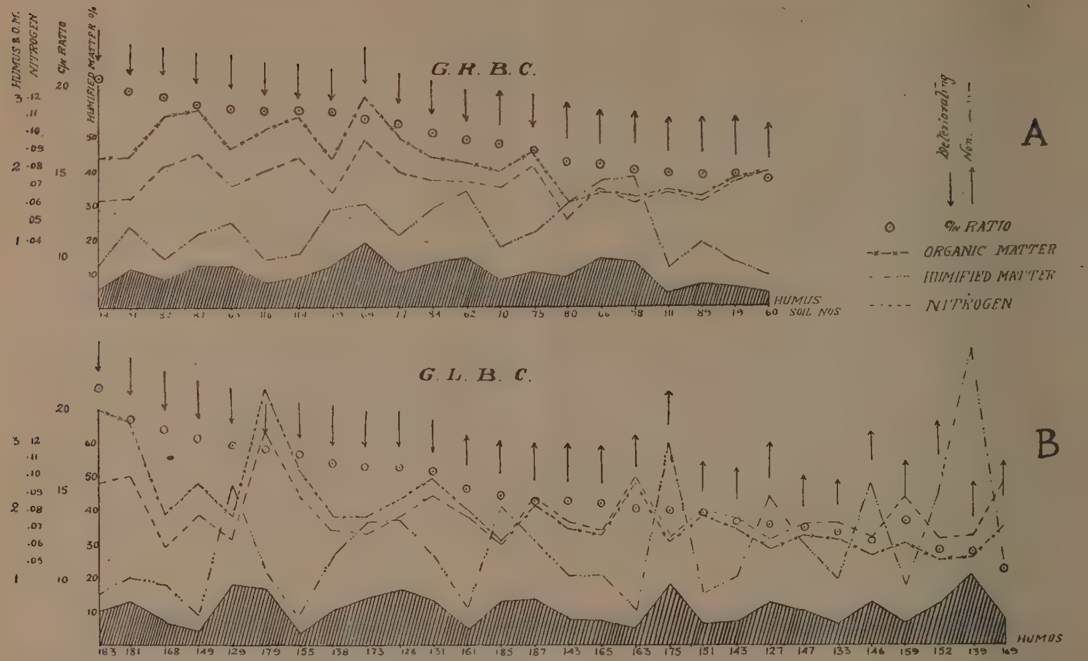

FIG. 6. Soil deterioration as indicated by carbon : nitrogen ratios and associated soil properties. (Godavari Canals)

(*b*) All the plots selected had cane in the previous year, and crops harvested either in January or February (of the year of sampling) so that the periods intervening between the harvesting and sampling were almost the same in all cases.

(*c*) Samples were taken mostly from lands where cotton was standing ; in some cases the land was either under *jowar* or *bajri* but in no case leguminous crop was there.

(*d*) Composite sample was made out of 10 individual first foot samples taken at random in each plot and analysed for important soil properties.

For the calculation of soil-fertility status (with reference to cane crop) nitrogen required to produce a 40-ton crop has been taken as an index figure. The soil numbers were arranged in order of descending fertility (i.e. requiring more N to produce a 40-ton crop) and corresponding soil properties entered below each soil number. The first 15 soils were arbitrarily taken to form a 'more fertile group' (Group I) whereas the rest put in a 'less fertile group' (Group II) to study the variations from the mean soil property (mean value for 31 soils) in each of these groups. In order to economize space only these final results are given in Table III.

When contradictory results are not obtained in the two groups, the results are taken to represent the fertility trend of the soils. Results are briefly stated below :

p*H in water.* In general, soils having *p*H values lower than 8·4 are more fertile than those possessing higher values.

p*H in* N *KCl.*—Similarly for *p*H in KCl, values higher than 7·4 indicate lower fertility status.

Calcium carbonate. In the case of calcium carbonate it appears that more fertile soils are associated with lower carbonate contents ($<5\cdot2$ per cent).

Available phosphate. Higher available phosphate (>0.07 per cent) contents indicate better fertility status of soils.

Water-holding capacity. Soils possessing greater moisture-holding capacities (<65 per cent) are usually those which are more fertile.

Nitrogen, nitrate, clay, exchange calcium and rate of increase in electrical conductivity show contradictory results in the two groups and hence no conclusion could be drawn.

In the case of available potash and humus, fertile soils are associated with lower K_2O ($<0\cdot03$ per cent) and lower humus ($<0\cdot8$ per cent) which fact cannot be explained at present.

From the above it will be apparent that although there is no strict relationship between soil fertility and the various soil factors, there is a

TABLE III

Frequency table showing the number of cases occurring above and below the mean values of soil properties in the 'more fertile' (Group I) and 'less fertile' (Group II) soil groups—Nira Left Bank and Godavari Canals

Soil properties	Mean value for 31 soils	Group I (More fertile soils) No. of cases out of 15 soils		Group II (Less fertile soils) No. of cases out of 16 soils	
		Values above the mean	Values below the mean	Values above the mean	Values below the mean
pH in water	8·39	5	10	9	7
pH in N. KCl	7·37	6	9	10	6
Calcium carbonte	5·19 per cent	6	9	8	8
Nitrogen	0·083 per cent	6	9	7	9
Available phosphate	0·069 per cent	10	5	7	9
Available potash	0·030 per cent	5	10	10	6
Nitrate	0·296 mg. per 100 gm. soil	7	8	4	12
Humus	0·83 per cent	6	9	10	6
Clay	53·23 per cent	7	8	7	9
Maximum water holding capacity	64·71 per cent	8	7	6	10
Exchangeable calcium	56·16 m.e. per cent	8	7	10	6
Rate of increase in electrical conductivity	124·49 per cent	8	7	10	6

general trend in the case of at least five soil properties. Generally speaking the more fertile soils are characterized by lower pH values (both in water and N KCl) and lower calcium carbonate but higher available phosphate and higher water-holding power. Want of a closer relationship may be due to the fact that the variations in soil types may be responsible for the changes in the limiting values in soil properties beyond which the yields of cane crop are affected.

GENERAL DISCUSSION AND CONCLUSIONS

The question of the effect of crop-growing on soil fertility has attracted the attention of various workers. There are two aspects of this question to be considered: firstly there is the immediate effect or growing a crop on the succeeding crop, and secondly the ultimate effect on the soil as a result of long-continued crop-growing either singly or in rotation with other crops. In a previous paper [Basu and Sirur, 1943] the effect of various rotational and green manuring crops on the succeeding cane crop has been fully discussed with special reference to soil tilth and other fertility factors. In the present paper data have been presented on the long-continued effects of cane-growing on soil fertility as revealed by a survey of sugarcane soils of three major canals of the Bombay-Deccan. The present position of this work is briefly reviewed here.

General trend in soil fertility due to cane-growing

It has been pointed out in a previous communication [Basu, 1942] that although there is no single absolute method of assessig soil fertility it is nevertheless possible by adopting several methods at the same time to approach to a fair understanding of the fertility status of a soil. To determine the fertility changes due to cane-cropping the straight-forward means of analyzing soils from pairs of adjacent plots—one having cane for long time and the other where no cane was ever taken—had to be resorted to. The results of these soil changes are discussed under three broad heads: (*i*) Physical, (*ii*) Plant nutrients, and (*iii*) Biological status.

Among the physical properties studied, taking first the changes in the mechanical composition of soils it is interesting to observe that the percentage of clay has increased due to cane-growing on all the canals. Two explanations can be offered: (*a*) mechanical breakdown of the coarsel particles as a result of intensive agriculturar operations associated with cane-growing, and (*b*) addition of finer suspended materials from the irrigation water specially during the monsoon months. The decrease in silt on the Godavari Canals, however, can partly be accounted for by assuming mechanical breakdown of silt particles whereas in the case of the older canal (Nira Left Bank) where both clay and silt have increased it may be taken that this process of disintegration has extended to coarse and fine sand fractions as well.

Exchangeable bases (i.e. calcium and sodium which have been determined in this survey) show interesting relationship in all the canals. There has been a general increase in calcium colloid

while a fall is noticed in sodium colloid (though not in equal amounts) as a result of cane-growing. As can be expected the older canal has shown greater changes when compared with comparatively newer canals. That the increase in exchangeable calcium at the expense of the other bases including sodium, is a natural pedogenic process in these calcareous soils when brough under irrigation with proper drainage, has been dealt with at length previously [Basu and Tagare, 1943], and need not be discussed here further. This improvement in soil colloids is reflected in slight lowering in pH values in all cases. As in this survey we have avoided atcually waterlogged and salt-affected soils the lowering in soluble salts has been, in general, rather small.

As regards nutrient status, available soil data indicate that cane-growing has not exhausted the soil so far as total nitrogen and available phosphoric acid are concerned. On the other hand, in the majority of cases there has been increase in nitrogen, the results of the Godavari Canals showing statistical significance. This is not surprising when we consider the manuring doses. Normally a cultivator's dose of nitrogen in the manures applied comes to 400 lb. per acre, out of which 250 lb. N is given as top-dressing (200 lb. N as cake plus 50 lb. N as sulphate of ammonia) while the rest supplied by farmyard manure, the latter being, however, hardly available to the cane crop. Taking the data worked out by the Physiological Section of the Station, a 42-ton crop of POJ 2878 obtained on a top-dressing of 225 lb. N (in the case of Pundia it is slightly less) can remove 152 lb. N, 48 lb. P_2O_5, 300 lb. K_2O and 151 lb. CaO from the soil. The average yield of cane being round-about 40 tons on these canals we find that a little more than half of the nitrogen supplied by the cake and sulphate is utilized by cane while the rest is generally lost by leaching. Of the 150 lb. N supplied by farmyard manure 40 per cent remains in the soil according to our data of controlled experiments in the farm. The above manuring supplies in addition 211 lb. P_2O_5 and 181 lb. K_2O. Thus taking into consideration even the leaching down of P_2O_5 by irrigation water (which is about 40 lb. P_2O_5 annually) there remains a surplus of P_2O_5 in the soil. Potash reserve of soil is, however, tapped by cane-growing but as most of the Deccan soils are well supplied by potash this aspect has not received our attention in this paper. Lastly, coming to the consideration of losses of lime (carbonate) from soils we find a very heavy drain (about 4,000 lb. per acre per annum) from all canals although the quantity removed by crops is small. This is expected as the percolating water in cane fields is usually highly charged with carbonic acid due to intense root and bacterial activities.

Increase in the rate of electrical conductivit[y] in all the canals as a result of cane-growin[g] indicates that the biological conditions of thes[e] soils have been improved. On the Godava[ri] canals, where statistical examination of dat[a] has been possible, it is observed that wit[h] increasing number of years of cane-growin[g] this effect is more and more pronounced (i.e[.] highly significant for irrigation and years) Qualitatively it is also observed that this increas[e] is correlated more with the amount of manure[s] applied than with the inherent fertility of the soils Thus it appears that cane soils develop a greate[r] microbial activity due to the nature of manurin[g] practised, which consists mostly of bulky organi[c] matter. Respiration studies conducted on soil[s] from controlled experimental plots at the farm also show that cane-growing increases the micro[-] biological activities of soils even when no manur[e] is applied, but more so, when manured. Thi[s] increased microbial activity is naturally expecte[d] to be linked up with increased carbon (energ[y] material) in cane soils but unfortunately thi[s] comparative data for cane and non-cane plot[s] are not available for all canals. In the case of th[e] older canal—Nira—where it has been determined considerable increase in carbon is actually observed Humus (i.e. dilute alkali-soluble fraction) o[n] the other hand shows losses in all canals, an[d] this in all probability, can be explained as due t[o] excessive irrigation as practised by the cultivators which induces mobilization of humus in a[n] alkaline medium obtaining in the highly calcareou[s] soils of the Deccan canals.

Deterioration in cane soils and its causes

So far we have discussed the general tren[d] in soil fertility as a result of cane-growing. No[w] we shall examine what specific changes ar[e] observed when soils begin to show signs of deterio[-] ration, which is reflected in gradual lowering i[n] yields of cane per unit nitrogen. Among the variou[s] soil factors examined in this connectio[n] consistent results have been obtained in the cas[e] of carbon/nitrogen ratio, which shows defini[te] widening (usually greater than 15·0) in the cas[e] of deteriorating cane soils. Regarding the actua[l] nitrogen or carbon contents of these soils n[o] generalization can, however, be drawn as con[-] trary results are obtained in case of the Nira an[d] Godavari Canals. When we examine the aver[-] age nitrogen doses applied in the past for th[e] deteriorating and non-deteriorating soils of thes[e] canals the apparent anomaly becomes expl[i-] cable. These figures together with the averag[e] data of soil analysis are given in Table IV.

It will be seen that in the case of Nira Canal no[n-] deteriorationg soils have received greater nitro[-] gen than the deteriorating ones, while reverse

TABLE IV

Average data for nitrogen applied to deteriorating and non-deteriorating soils, and the nitrogen, carbon and humus contents of these soils—Nira Left Bank and Godavari Canals

		Average manure applied in terms of lb. of N	Nitrogen content of soil per cent	Organic carbon per cent	Humus per cent	Percentage Humified matter
Nira Left Bank Canal	D	345	0·073	1·233	0·42	21·60
	N-D	402	0·099	1·341	0·82	36·42
Godavari Right Bank Canal	D	428	0·076	1·438	0·55	22·31
	N-D	349	0·067	1·036	0·39	22·16
Godavari Left Bank Canal	D	474	0·082	1·467	0·57	24·16
	N-D	354	0·073	0·959	0·51	32·91

the case of both the canals of Godavari. This residual effect of higher manuring on the nitrogen and carbon contents is also reflected to a certain extent on the humus contents of these soils. The percentage humified matter on the other hand shows a characteristic lowering (with soil deterioration) in both the Nira and Godavari Left Bank, while in case of the Godavari Right Bank, in spite of higher humus contents of the deteriorating soils, the humified matter remains more or less constant. This fact indirectly shows that in the deteriorating soils losses suffered by the humified fraction of the total organic matter are greater probably due to injudicious irrigation resulting in greater leaching down of soluble organic constituents of the soil.

It has been shown previously [Basu and Vanikar, 1942] that the application of heavy dose of farmyard manure may lead to increased carbon/nitrogen ratio when the moisture saturation is kept at a high level. Under such a condition the algal growth in the soil is generally vigorous which has been shown to be associated with the ultimate increase in soil carbon. Increased moisture saturation in these cane fields may result from either over-irrigation or ill-drained condition of the soil or from both these factors. From our results of this survey it appears that the adoption of a suitable crop rotation (probably due to occasional cultivation and partial drying out of the soil) can counteract to a great extent this progressive increase in the carbon/nitrogen ratio of these soils and thus avert this calamity of falling cane yields.

On the Nira Left Bank Canal, where cane has been grown for a long time, it has been observed that in a very well-drained shallow soil (<2 ft. deep) even a two-year rotation of cane (one year cane with one year another crop) has been able to maintain the fertility of the soil while in a deeper soil (>4 ft. deep) a four-year ratation (one cane in four years) seems to be essential. From the Godavari Canal survey, it appears that a ratoon is far more exhausting than a plant cane crop. Thus two years of rest from cane-growing are found to be insufficient to maintain the fertility of a shallow soil where a crop of plant cane and a ratoon are taken. Although in a deeper soil for the same rotation a much longer rotation is expected for the maintenance of fertility, it is interesting to note that much depends on the actual drainage condition of such a soil, which is ultimately governed by the nature of 'B' horizon in a soil profile [Basu and Tagare, 1943]. For instance in an exceptionally well-drainaged deep soil type of the Godavari Left Bank (where the 'B' horizon consists of yellowish while alluival sands) it is found that even a four-year rotation with cane—ratoon and two other crops—retained the fertility intact. Similar instrances are not wanting even in the case of shallower soils where very trying rotations have proved successful. Thus in recommending the rotation of a soil for sugarcane cultivation it will be worthwhile to have a general survey of soils made for the types, in order to avert any disaster due to indiscriminate use of lands under perennial irrigation, without a sound policy of crop rotation based on scientific studies of the soil.

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STUDIES ON BUNDELKHAND SOILS

I. THE GENETIC TYPES

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GENERAL

THE part of the United Provinces lying south-west of the river Jumna is known as Bundelkhand. The soils of this tract are entirely different from those of the province as a whole, since the tract differs geologically from the rest in being non-alluvial in nature. The district of Jhansi from where the soils reported in this paper were collected lies in the extreme south-west corner of the tract between the parallels of 28°11′ and 25°51′ north latitude and 78°10′ and 79°25′ east longitude. This part is a most representative tract of the whole region due to its peculiar topography, and the various soil types occurring in the whole of Bundelkhand can easily be found in this district.

The general landscape of the Bundelkhand tract is that of a bare undulating plain with irregular rocky hills converging to a level expanse of black soil towards the north reaching up to the river Jumna. On the extreme south and south-west lie the Vindhya ranges. The general slope of the country is from north to south and as one passes through the level plains on the south of the Jumna to the rocky hills, the fertile black soil converges into coarse-grained red soil interspersed with brownish to black patches.

Geologically the whole of the Bundelkhand tract is occupied by gneiss. The formation consists of massive granite rocks traversed by gigantic quartz reefs forming the hill ranges. At times sandstones, limestones and slates are also to be met with. Some of the beds are highly ferruginous and iron has become localized at the surface 'probably due to lateritic action'. The only other geological formation found in the tract is the cretaceous sandstones of the Lameta group [Drake-Brokeman, 1909].

(i) *Soils*

The soils can be classified into two broad divisions, viz. (*a*) black soils and (*b*) red soils. The black soils are usually very adhesive when wet and expand and contract to a remarkable degree, thus becoming fissured in the hot season. These are locally known as *mar* and *kabar*. *Mar* is usually less clayey than *kabar*, but both these types are highly retentive of moisture and could be cultivated without much irrigation. These are the typical analogues of the so-called black cotton soils of Central India popularly known as the *regur* soils.

Amongst the red soils there are two types locally known as *parwa* and *rakar*. *Parwa* is a brownish grey soil varying from a good loam to sandy or clayey in texture and is a fairly good soil which responds easily to manure and irrigation. *Rakar* is the true red soil which is generally worthless for cultivation. It is the eroded soil of the tract and is thus usually found on higher elevations. In general the red soils are found more towards the south of the tract where it adjoins the Central Indian hills.

(ii) *Vegetation and agriculture*

The natural vegetation of the tract consists of grasses and shrubs. Trees are usually absent, but at times *ber* (*Ziziphus rotundifolia*) and *dhak* (*Butea frondosa*) grow on better types of land. Spear grass is the most common grass of the locality although better varieties like *anjan* (*Pennisetum cenchroides*) may be found in low-lying areas. In places having *kabar* and *mar* soils *kans* (*Saccharum spontaneum*) grows wild and its eradication is a serious problem.

The general agriculture of the tract is of a very low order. The poor nature of the soil and scarcity of water are the two chief factors responsible for this condition. The black soil areas are mostly cultivated; whereas the less fertile red soils are cultivated only if irrigation facilities are available. Most of the cultivation is done during the *kharif* and little is possible during the *rabi* except on good black soil. *Jowar*, smaller millets and *til* are the principal *kharif* crops, and wheat, gram and linseed the principal *rabi* crops. Wheat and *jowar* are generally put on better soils and gram and smaller millet occupy soils of lesser fertility.

(iii) *Climate*

The climate of Bundelkhand, as might be expected from the rocky nature of the tract, the rapid drainage, the absence of jungle and the depth of water-level, is characterized by exceeding dryness and heat considerably above the average of the province. May and June are intensely hot and the rainy season is also at times marked

by unusually high temperatures. In the cold weather the air is dry and chilly although frosts are usually absent. The mean annual temperature is 79·0°F. and the mean annual rainfall 36·4 in. The coldest month is January with an average of 62°F. and hottest is May or June with 94·5°F. The maximum temperature in hot weather is at times recorded as high as 116°-120°F.

The usual meteorological data for Jhansi proper are given in Table I.

TABLE I

Average monthly meteorological data for Jhansi

Month	Temperature			Rainfall		
	Max. (°F.)	Min. (°F.)	Mean (°F.)	Total rainfall (in.)	No. of rainy days	Relative humidity (per cent)
January	76·4	37·3	62·0	0·56	1·2	54·3
February	81·4	41·4	68·0	0·40	0·8	45·6
March	93·1	49·4	78·0	0·23	0·5	36·9
April	104·2	60·9	88·0	0·14	0·5	30·2
May	108·3	68·1	94·5	0·24	0·7	31·9
June	102·8	71·3	92·8	4·43	5·8	48·5
July	91·2	71·9	83·9	11·81	13·1	77·8
August	88·9	71·0	82·6	11·50	12·7	80·5
September	91·7	68·4	82·2	6·08	6·8	74·2
October	92·9	50·0	79·9	0·63	0·9	53·6
November	85·3	42·3	71·8	0·07	0·1	45·2
December	78·4	40·7	63·9	0·28	0·8	51·0
Mean	91·2	39·1	79·0	36·37	43·9	52·3

Note —Monthly mean temperatures are the averages of 16-18 years, whereas rainfall figures are the average of 47 years

It will be seen that the rainy season lasts from the middle of June to the middle of September and that during this period practically the whole annual precipitation takes place. It may be mentioned that rains usually come in heavy downpours and thus bring about considerable erosion. During the rainy season one finds alternately hot and wet periods which are responsible for considerable weathering of the soil and leaching away of the weathered products. Winter rains are practically absent. Lang's [1915] rain factor for the locality is 34·9 mm. per degree centigrade and Meyer's [1926] N.S. quotient is 78·8, showing that the climate may be characterized as semi-arid.

(*iv*) *Literature*

Literature on the black and red soils of India is extremely meagre. Sahasrabudhe [1929] in his note on soils of the Bombay Presidency compiled only the available scattered data on those soils. Basu and Sirur [1938] are the pioneer workers who scientifically surveyed the soils of the Deccan canal area and classified them on modern pedological principles. Their work is unique, for it throws considerable light on the chief pedogenic processes responsible for the different types of *regur* soil found in the Bombay-Deccan.

(*v*) *Technique employed*

A number of pits were dug at the Government Cattle Farm, Bharari, Jhansi, at sites which were considered representative of the different soil types of the tract. The samples of soil were collected horizon-wise. Observations in regard to the visual characteristics of each horizon were recorded *in situ*, particularly with regard to colour, texture, structure, depth and hardness. A number of such profiles from each type were examined and results of the selected ones have been presented in the body of the paper.

The usual laboratory methods for the analysis of the hydrochloric acid extract on 2 mm. samples of soil were followed. *p*H was determined colorimetrically, total exchangeable bases by the method of Williams [1929] and exchangeable calcium by Hissink's sodium chloride method [1923]. Mechanical analysis was done by the International pipette method after pre-treatment with hydrogen peroxide and dispersion by sodium hydroxide. The separated clay fraction was analysed after fusion with sodium carbonate according to the method of Robinson as described by Wright [1939].

EXPERIMENTAL

From the results of the visual observations on the profile and the analytical data obtained it

seems obvious that the soils of the district of Jhansi in particular and of the Bundelkhand tract in general contain amongst other soil types three distinct genetic types depending upon the developmental characteristics of the profiles. These three types have been mentioned in the text of the paper as Types I, II and III. Morphological, chemical, mechanical and physico-chemical data of the three types have been presented under each head. It will be observed that differences in the types are mainly due to differences in topographical conditions and subsequent differences in weathering and leaching. The data for the three types are presented separately to enable a comparison being made among them.

Type I

Morphological. The pit was situated at a higher level than the surroundings. The soil was very coarse and compact, having a reddish brown colour. The sample was obtained from an uncultivated portion for profile No. 1 and from near a recently cultivated portion for profile No. 2 which was also at a slightly lower level as compared to the site at which pit No. 1 was dug.

TABLE II

Visual characters

Horizon	Depth	Sample depth	Description
		Profile No. 1	
I	0 in.—7 in.	0 in.—7 in.	Brown soil with loose sandy texture more or less crumby structure, presence of some roots, no colour with phenolphthalein; no reaction with HCl
II	7 in.—5 ft. 5 in.	7 in.—2 ft. 5 in. 2 ft. 5 in.—3 ft. 11 in. 3 ft. 11 in.—5 ft. 5 in.	Red hard compact soil; coarse grained; impregnated with red particles of iron oxide; no colour with phenolphthalein; no reaction with HCl
III	5 ft. 5 in.—6 ft.	5 ft. 5 in.—6 ft.	Parent material; hard and rock like big stones
		Profile No. 2	
I	0 in.—5 in.	0 in.—5 in.	Reddish yellow coarse grained soil loosely packed; sparse growth of roots; no colour with phenolphthalein; no reaction with HCl
II	5 in.—3 ft. 2 in.	5 in.—1 ft. 9 in. 1 ft. 9 in.—3 ft. 2 in.	Dark brown soil; loosely packed with *murrum* with big-sized stones towards the bottom; no reaction with phenolphthalein; no reaction with HCl
III	3 ft. 2 in.—4 ft.	3 ft. 2 in.—4 ft.	Big-sized stones loosely held

A consideration of the morphological data indicates that the soil is a coarse-grained material and that good soil lies on the top as a superficial cover up to a depth of a few inches only. The horizons are very clear-cut and the weathered parent rock can be met with only within 4 to 5 ft. of the soil. Topographically such soils are found at elevated spots and at the foot of hilly portions of the area. In general appearance these soils look like eroded soils.

In Table III are presented the data for the composition of the hydrochloric acid extract of the soil material.

Moisture and loss-on-ignition figures are more or less uniform throughout the profile with a tendency to be low at the surface layer due probably to its lower clay content. The first horizon is highest in insoluble residue and it decreases in the next only to increase again in the last horizon. Soluble silica in profile No. 2 is low in the top horizon. This indicates that the products of the disruption of the silicate complex have been washed down the profile and this fact is further corroborated by a study of the distribution of sesquioxides. Both iron and alumina are low in the top horizon and increase to more or less a constant level in the next layers. Leaching is further indicated by a gradual washing of both lime and magnesia to lower depths. Profile No. 1 is markedly low in potash, but the other profile is not so poor. Water-soluble salts are very low. The mechanical analysis data are tabulated in Table IV.

TABLE III

Analysis of the hydrochloric acid extract

(Per cent air dry basis)

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Moisture	0·61	2·75	2·60	0·68	1·47
Loss on ignition	2·20	5·95	5·17	5·62	3·47
Total insolubles	91·46	74·20	76·66	76·02	81·49
Sesquioxides	4·74	14·08	13·42	12·62	10·63
(a) Fe_2O_3	1·90	4·45	4·09	4·61	3·95
(b) Al_2O_3	2·85	9·53	9·25	7·93	6·60
CaO	0·49	0·97	0·73	0·84	0·75
MgO	0·58	0·82	1·01	1·66	1·32
K_2O	traces	traces	traces	traces	traces
P_2O_5	0·09	0·10	0·08	0·08	0·08
Total water solubles	0·09	0·04	0·08	0·09	0·10

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Moisture	2·62	3·75	2·72	2·04
Loss on ignition	3·67	4·93	3·49	3·93
Total insolubles	72·81	62·40	67·76	76·26
(a) Soluble SiO_2	15·96	23·60	20·37	20·43
Sesquioxides	17·18	25·49	19·38	21·43
(a) Fe_2O_3	5·84	8·56	6·84	9·36
(b) Al_2O_3	11·30	16·86	12·44	11·94
CaO	0·69	1·02	2·02	2·41
MgO	0·81	1·99	2·09	1·09
K_2O	1·13	1·04	0·64	1·98
P_2O_5	0·05	0·07	0·10	0·13
Total water solubles	0·06	0·06	0·08	0·08
$\frac{SiO_2}{R_2O_3}$ (mol)	1·86	1·85	2·25	2·12
$\frac{SiO_2}{Al_2O_3}$ (mol)	2·66	2·48	3·06	3·10
$\frac{Al_2O_3}{Fe_2O_3}$ (mol)	2·92	2·97	2·75	1·93

TABLE IV

Mechanical analysis (2 mm. sample)

(Per cent air dry basis)

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2 ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Coarse sand	43·37	24·85	32·30	42·23	53·85
Fine sand	40·38	22·83	26·36	20·16	23·81
Silt	15·10	21·25	17·10	18·60	22·42
Clay	5·05	18·00	13·05	10·15	3·75

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Coarse sand	21·10	22·35	50·32	44·46
Fine sand	29·75	24·29	21·60	20·89
Silt	15·45	16·05	11·10	11·30
Clay	31·25	36·75	13·60	19·65

The highly coarse nature of the soil is indicated by a very high coarse sand content throughout the whole profile. Clay and silt together constitute only about 25-30 per cent of the whole soil except in the two top layers of profile No. 2 which had received eroded washings from the neighbouring plots as a result of artificial embankment at a distance of nearly a furlong or so. There is a slight eluviation of clay from the top horizon which makes the lower horizons more compact. In general, the soils appear to have been subjected to high erosion whereby the finer materials have been washed away. Soils represented by profile No. 2 are, however, texturally better than those represented by the other profile. It seems that much improvement in the physical condition of soils of this type can be brought about by simply checking erosion. The data for the physico-chemical analysis are presented in Table V.

TABLE V

Physico-chemical analysis

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2 ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Moisture (natural) per cent	2·44	6·69	9·03	6·12	3·60
Moisture equivalent per cent	12·23	25·92	27·97	15·18	17·70
Water-holding capacity per cent	32·75	57·10	33·06	53·48	42·44
*p*H in *N*-KCl	6·0	6·0	6·0	7·2	7·2
Total nitrogen per cent	0·057	0·066	0·049	0·031	0·029
Total carbon per cent	0·47	0·35	0·82	0·35	0·47
C/N ratio	8·25	5·30	16·7	11·3	16·2
Total exchangeable bases m.e. per cent	5·0	15·0	14·48	16·18	14·00
Total exchangeable calcium m.e. per cent	5·0	14·32	14·0	15·12	13·24
Per cent Ca of the total bases	100·0	95·4	96·5	93·5	94·5

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Moisture (natural) per cent	1·38	13·37	11·89	13·94
Moisture equivalent per cent	27·3	29·0	20·8	24·7
Water-holding capacity per cent	44·04	49·09	35·80	40·03
*p*H in *N*-KCl	6·5	6·9	7·3	7·5
Total nitrogen per cent	0·021	0·049	0·034	0·006
Total carbon per cent	0·79	0·57	0·21	0·25
C/N ratio	37·3	11·6	6·2	41·6
Total exchangeable bases m.e. per cent	18·40	27·36	29·44	26·74
Total exchangeable calcium m.e. per cent	18·32	24·00	19·52	19·68
Per cent Ca of the total bases	99·5	81·5	66·3	73·8

It is evident from Table V that *p*H increases with depth and that the top horizons are slightly acidic (6·0—6·5). This indicates acid leaching of the entire profile. The nitrogen content is poor (0·02—0·05 per cent) and the poor top layer lies on a subsoil comparatively richer in nitrogen. Afterwards nitrogen decreases to a very low figure. C : N ratios are erratic. The organic matter content and base status of the profile is low, specially so in profile No. 1, but the exchange complex is more or less fully saturated with calcium—a fact which gives a fairly good crumb structure to the top soil. Although the absence of a zone of calcium carbonate accumulation has given these profiles an acidic character, it is significant to note that the degradation has not proceeded to the extent so as to make the exchange complex low in calcium.

The separated clay fraction was analysed for its chief ultimate constituents in the case of profile No. 2. The results of this analysis are presented in Table VI.

It seems that there is a slight eluviation of silica from the top horizon. Alumina also seems to be leached down but iron accumulates in the top layers. $SiO_2 : R_2O_3$ ratio increases with depth showing greater leaching of silica as compared to sesquioxides. Similar results are obtained if the ratios are calculated in the bulk sample of the soil (Table III). $SiO_2 : Al_2O_3$ ratio in the clay fraction and in the soil also shows a greater mobility of silica as compared to alumina In the clay fraction, however, the $Al_2O_3 : Fe_2O_3$ ratio increases with depth as a result of accumulation of iron in the top layers This may be responsible for the characteristic red colour of the top soil.

Type II

Morphological. The pit was situated at a comparatively lower level than the areas at which pits representing Type I were dug. The soil was brownish red in colour and looked better in texture. The samples were obtained from a recently cleared jungle area.

TABLE VI

Ultimate analysis of clay

Profile No. 2

Horizons	SiO_2 per cent	R_2O_3 Per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—5 in.	35·74	31·77	13·46	18·31	2·25	3·32	2·13
5 in.—1 ft. 9 in.	37·89	34·40	14·53	19·87	2·21	3·24	2·15
1 ft. 9 in.—3 ft. 2 in.	37·63	31·15	12·40	18·75	2·41	3·41	2·37
3 ft. 2 in.—4 ft.	42·15	32·18	12·36	19·82	2·59	3·62	2·52

TABLE VII

Visual characters

Profile No. 3

Horizon	Depth	Sample depth	Description
I	0 in.—10 in.	0 in.—10 in.	Loose, yellowish grey soil; single grained; no reaction with HCl
II	10 in.—3 ft. 9 in.	10 in.—2 ft. 3½ in. 2 ft. 3½ in.—3 ft. 9 in.	Hard and compact; reddish brown soil with big roots; no reaction with HCl
III	3 ft. 9 in.—6 ft.	3 ft. 9 in.—4 ft. 10½ in. 4 ft. 10½ in.—6 ft.	Hard soil with *kankar*; reddish grey colour; looks more clayey; vigorous reaction with HCl

As compared to Type I this profile shows greater depth and the most important feature is the presence of a zone of calcium carbonate accumulation in the form of *kankar* layer at the bottom. The colour of the soil is also brownish as compared to Type I which is redder in shade.

Considering the results of the analysis of hydrochloric acid extract presented in Table VIII it is evident that moisture and loss-on-ignition figures are lower in the top horizon than those for the bottom layers, indicating a slight eluviation of colloidal matter. Insoluble residue decreases with depth although soluble silica is more in the second and third layers. There is a slight leaching of the sesquioxides from the first layer and they accumulate uniformly in other layers, iron being more affected than alumina; although in the case of the latter ingredient there seems to be a gradual accumulation with depth. Lime has been washed down and accumulates in lower horizons, whereas, magnesia does not seem to be so affected. Water-soluble salts are more or less uniform throughout the profile.

As compared to Type I, these figures show that although there has been a translocation of the weathering products of silicate complex to lower depths, these are not so pronounced as in Type I. The presence of calcium carbonate layer at the bottom has probably given greater stability to this complex. This is a typical feature of calcium soils. The results of the mechanical analysis of the profile are given in Table IX.

TABLE VIII

Analysis of hydrochloric acid extract

(Per cent air-dry basis)

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3ft. 9in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Moisture	0·70	1·37	1·73	1·48	1·28
Loss on ignition	1·45	2·25	2·04	0·92	1·00
Totoal insolubles	88·13	82·97	80·81	77·61	64·72
SiO_2	10·33	12·59	13·98	11·56	12·89
Sesquioxides	7·47	10·52	12·70	13·28	12·79
Fe_2O_3	2·76	4·64	4·80	4·18	4·34
Al_2O_3	4·65	5·76	7·77	8·98	8·35
CaO	0·56	0·67	0·83	6·71	10·44
MgO	0·16	0·47	0·10	0·10	0·05
K_2O	0·08	0·19	0·16	1·62	0·58
P_2O_5	0·07	0·12	0·13	0·12	0·10
Total water solubles	0·11	0·08	0·08	0·17	0·10
SiO_2/Al_2O_3	3·77	3·56	3·06	2·19	2·62

TABLE IX

Mechanical analysis (2 mm. sample)

(Per cent air-dry basis)

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3 ft. 9 in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Coarse sand	8·29	4·54	2·21	1·67	1·07
Fine sand	60·05	53·91	50·39	39·32	36·88
Silt	10·80	14·50	16·10	14·92	19·05
Clay	14·55	25·45	28·25	25·43	20·25

With the exception of the first layer, silt and clay together constitute nearly 40 per cent of the soil. The texture of this type is, therefore, loamy and unlike that of Type I is more desirable for cultivation. Coarse sand fraction is low, whereas fine sand fraction is over 50 per cent in the three top layers. There is a slight eluviation of clay from the first to the second layer.

TABLE X

Physico-chemical analysis

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3 ft. 9 in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Moisture (natural) per cent	7·24	10·59	8·93	2·98	9·56
Moisture equivalent per cent	20·90	28·30	30·80	25·50	23·50
Water holding capacity per cent	40·00	48·30	48·30	47·60	46·00
*p*H in *N*-KCl	7·4	6·4	6·9	7·1	7·3
Total nitrogen per cent	0·060	0·056	0·053	0·039	0·032
Total carbon per cent	0·39	0·31	0·15	0·17	0·13
C/N ratio	6·5	5·5	2·8	4·3	4·1
Total exchangeable bases m.e. per cent	11·68	14·72	17·04	18·80	13·0
Total exchangeable calcium m.e. per cent	9·6	14·13	16·70	16·16	12·8
Per cent Ca of the total exchangeable bases	82·0	96·0	98·0	86·0	98·5

A study of the data presented in Table X shows that with the exception of the second layer the *p*H of the profile is within the neutral range. Total nitrogen content and the organic matter content are highest at the top and decrease downwards. The base-exchange status is more or less similar to that of Type I and the exchange complex is mainly saturated with calcium, thus giving proper tilth to the soil.

The results of the clay analysis (Table XI) point clearly to some of the striking differences between the soils belonging to Type I and those belonging to Type II. In Type I it was observed that there is a slight migration of both silica and alumina from top to bottom layers, but this fact is not observed in the present case. On the contrary, silica and alumina are highest in the first layer. The immobility of iron is a peculiar feature of this type. Within limits the $SiO_2 : Al_2O_3$ ratio is constant throughout the profile. These are the chief characteristics of calcium soils and the presence of the *kankar* layer in the lower depths is probably responsible for these factors. The absence of this layer in Type I made silica and sesquioxides a bit mobile. In the case of the whole soil, however, the ratio $SiO_2 : Al_2O_3$ shows a slight leaching of silica as compared to alumina (Table VIII).

Type III

Morphological. This profile has developed as a result of restricted drainage and was situated in an area which was comparatively low lying.

TABLE XI

Ultimate analysis of clay

Profile No. 3

Horizons	SiO_2 per cent	R_2O_3 per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—10 in.	44·61	36·81	11·11	25·70	2·31	2·95	3·63
10 in.—2 ft. 3½ in.	42·55	33·80	11·30	22·50	2·43	3·22	3·12
2 ft. 3½ in.—3 ft. 9 in.	43·42	34·66	10·90	23·76	2·40	3·11	3·42
3 ft. 9 in.—4 ft. 10½ in.	39·77	32·04	10·00	22·04	2·38	3·07	3·46
4 ft. 10½ in.—6 ft.	43·02	34·69	11·10	23·59	2·39	3·10	3·33

TABLE XII

Visual characters

Profile No. 4

Horizons	Depths	Sample depths	Description
I	0 in.—4 ft.	0 in.—1 ft. 5 in. 1 ft. 5 in.—3 ft. 3 ft.—4 ft.	Deep black hard stiff clay ; cracks on wetting ; sticky and impervious. No reaction with HCl in the top layers, but slight reaction in the bottom
II	4 ft.—5 ft. 5 in.	4 ft.—5 ft. 5 in.	Compact *bajri* (clay interspersed with lime nodules) of grey colour vigorous reaction with HCl

The colour of the soil is deep black and the soil is very clayey. No very sharp colour distinctions between the different horizons were obtainable. The soil shows calcareous nature, specially in the bottom layers.

As will be shown presently, the first and third layers are comparatively more clayey. This has resulted in greater accumulation of sesquioxides, particularly alumina, in these layers as compared to the second and the fourth. Insoluble residue decreases with depth. Soluble silica also decreases with depth. Moisture is more or less uniform throughout, but is decidedly higher than in Types I or II. This indicates higher hygroscopicity of this type as a result of greater clay content. Lime has accumulated

in lower layers although the distribution of magnesia is irregular. Water-soluble salts are slightly high, being nearly 0·1-0·2 per cent with a tendency to accumulate with depth.

TABLE XIII

Analysis of hydrochloric acid extract

(Per cent air-dry basis)

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Moisture	4·06	4·42	4·35	3·47
Loss on ignition	3·75	3·89	3·93	4·46
Total insolubles	74·42	74·45	70·28	64·53
SiO_2	25·84	20·02	20·49	17·13
Sesquioxides	15·26	13·46	16·03	12·97
Fe_2O_3	5·52	5·68	6·04	5·32
Al_2O_3	9·68	7·71	9·88	7·51
CaO	1·15	1·15	2·40	7·50
MgO	2·43	1·57	1·83	2·07
K_2O	0·62	0·66	1·24	1·00
P_2O_5	0·06	0·07	0·11	0·14
Total water solubles	0·08	0·10	0·10	0·22

TABLE XIV

Mechanical analysis (2 mm. sample)

(Per cent air-dry basis)

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Coarse sand	6·89	10·01	6·37	4·91
Fine sand	25·24	23·21	21·57	31·96
Silt	24·20	24·80	25·90	29·15
Clay	43·30	40·75	43·40	37·20

The predominantly clayey character of the soil is clear from the results of its mechanical analysis tabulated in Table XIV. The clay and silt content is over 60 per cent throughout. This confers on the soil its distinguishing character of cracking when wet and forming big fissures on drying. The first and the third layers are slightly more clayey than the second and the fourth. The physico-chemical data are presented in Table XV.

TABLE XV

Physico-chemical analysis

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Moisture (natural) per cent	15·75	20·27	20·16	23·36
Moisture equivalent per cent	35·6	35·9	31·5	31·2
Moisture-holding capacity per cent	48·57	43·46	50·05	40·33
*p*H in *N*-KCl	6·7	7·3	7·3	7·2
Total nitrogen per cent	0·031	0·022	0·017	0·015
Total carbon per cent	0·50	0·46	0·39	0·14
C/N ratio	16·1	20·9	22·9	9·3
Total exchangeable bases m.e. per cent	25·64	30·82	66·49	96·92
Total exchangeable calcium per cent	25·04	25·12	24·16	17·92
Per cent Ca of the total exchangeable bases	97·7	81·5	36·4	18·5

Natural moisture is high, showing better water-retentivity of the soil; and greater moisture-equivalent figure suggests higher colloidal content. *p*H is on the whole neutral and tends to become alkaline with depth. Nitrogen is very low and organic matter is fairly high, thus giving a wider C/N ratio. The higher colloidal content confers on the soil greater base status and the total exchangeable bases are, therefore, fairly high and increase downwards. Exchangeable calcium is better in the first two layers, giving per cent saturation with this cation as 97 and 81, than in the bottom layers where it decreases rapidly reaching such a low value as 18·5. This decrease in the calcium saturation of the exchange complex of the soil with depth makes the subsoil more impervious to water and interferes with its natural drainage. The top layers, however, do not show any degradation of the exchange complex with respect to calcium. As in other cases the separated clay fraction was analysed for its constituents after fusion with sodium carbonate and the results obtained are presented in Table XVI.

The analytical results of the first two layers suggest that there is migration of silica and sesquioxides from the first to the second layer. Below the second layer, however, both silica and sesquioxides become within limits constant. $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios decrease

TABLE XVI

Ultimate analysis of the clay fraction

Profile No. 4

Horizon	SiO_2 per cent	R_2O_3 per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—1 ft. 5 in.	40·81	30·88	9·40	21·48	2·52	3·23	3·60
1 ft. 5 in.—3 ft.	50·39	39·43	11·24	28·19	2·49	3·06	4·04
3 ft.—4 ft.	36·31	28·40	7·80	20·60	2·41	2·99	4·14
4 ft.—5 ft. 5 in.	34·13	28·43	8·00	20·43	2·28	2·84	4·01

with depth, showing greater mobility of sesquioxides, particularly alumina, with respect to silica. These results become quite interesting when compared with those obtained for Type I (Table VI) where both $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios are found to increase with depth showing greater mobility of silica. $Al_2O_3 : Fe_2O_2$ ratio increases in the second layer and then becomes constant.

GENERAL DISCUSSION

A joint consideration of the data presented for the three genetic types of soil described in the present paper points clearly to the fact that climate has played a great part in the development of the soils of the Bundelkhand tract. The intensely hot summers followed by heavy undistributed rainfall during greater part of the monsoons considerably favour weathering and consequent leaching away of the weathered products. This fact coupled with the peculiar topography of the region gives rise to entirely different types of soil formed under heavy, partial and restricted drainage. The soils formed under free drainage are completely devoid of the more soluble constituents like alkali metals, and more or less complete removal of alkaline-earth metals also takes place. There is a further tendency towards leaching of silica and consequent laterization. However, the silica : alumina ratio is too high to permit their classification under laterites. The colour of these soils is red, and they are usually met with on elevated spots.

With a slight restriction in drainage as a result of topography alkaline-earth metals accumulate in the lower horizons and the mobility of silica and sesquioxides is also checked. Under impeded drainage an altogether different type of soil is produced which has a black colour and is highly clayey. The formation of these three types can, therefore, be explained on the basis of the topographical conditions of the locality. Thus red soils (Type I) are found at elevated spots, brown soils (Type II) on level plains and black soils (Type III) in valleys and depressions. The great part played by topography in the formation of the soils of the Deccan canal area was similarly shown by Basu and Sirur [1938] and in the case of those of the Kumaon Hills by Mukherji and Das [1940].

Basu and Sirur in the course of their studies on the soils of the Deccan canal area showed a parallelism between those soils and the Russian tschernozems and called the Deccan canal soils as 'tropical immature tschernozems'. The Bundelkhand soils studied in the present paper also look quite similar to the soils studied by Basu and Sirur, and a brief comparison between the two may be quite interesting.

Basu and Sirur divided the Deccan canal soils into two broad sub-divisions, viz. (*a*) soils formed under free drainage and (*b*) soils formed under restricted drainage. It seems that Type I of the present studies has not been met with in the Bombay-Deccan by these workers. Type II closely resembles the 'H type' of Basu and Sirur although there are certain minor points in which the two soils differ. H type of Basu and Sirur has a very shallow depth and the soils are more clayey and have a greater salt concentration than those of the Bundelkhand soil represented by Type II. The total base-saturation capacity is higher for Bombay soils of H type although the per cent saturation with calcium is lower as compared with Type II of Bundelkhand. It seems that the higher water-table (12 ft.) in Bombay is probably responsible for these differences, since in Bundelkhand the water-table where the present type of soils occur is never less than 30 ft.

Type III described in the present paper resembles to some extent the features of type B or C of Basu and Sirur. In the soils studied by these authors, however, considerable quantities of soluble salts were found and the per cent saturation of calcium in the exchange complex was always low. In the present case, soils belonging to Type III neither contain so much soluble salts nor show any degradation of the exchange complex at the surface horizons, although they are not so calcareous as the corresponding soils of the

Bombay-Deccan formed under restricted drainage. These differences have rather important bearing on the agricultural aspects of these soils, since in the Bundelkhand tract degraded black soils are never very common and the problem of '*chopan* formation' found in the Bombay-Deccan is seldom serious. This may be due to the fact that intensive canal irrigation has not as yet been introduced in Bundelkhand and dry farming is still practised in that locality.

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Summary

Four soil profiles developed under semi-arid conditions have been examined near Jhansi in the Bundelkhand tract.

The morphological, chemical and other data for these profiles have been presented and discussed.

Topography has been found to modify not only the colour of the soils, but also their texture and composition.

The SiO_2/Al_2O_3 ratio was about 3·2 in the clay fraction of each type and did not show any appreciable variation with depth.

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A FIELD METHOD OF DETERMINING CLAY CONTENT OF SOILS

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The clay fraction is the most important constituent of soils and its estimation in a simple way, which could be adopted as a field method, has been under examination. The Chiano-Hydrometer [Puri and Puri, 1939] is the most suitable apparatus for the detailed examination of the mechanical composition of soils. It is, however, essentially a laboratory method, with limited application in the field. As the detailed mechanical analysis is not needed for most purposes the development of a field method by which only the clay fraction could be estimated was considered desirable.

Turbidity of a clay suspension has been used as a measure of its concentration. The well-known nephelometer method consists in comparing the turbidity of the unknown suspension with that of the standard. As this apparatus is too elaborate it is not suitable for the purpose in view. A simple method that suggests itself is to lower an object gradually in a largely diluted clay suspension till it becomes invisible to the eye placed at a certain distance above the suspension. A standard clay suspension can be used for calibrating such an apparatus. The greater the concentration of the suspension the smaller will be the distance *d*, through which the object will have to be lowered. There may not, however, be any simple proportionality between the clay percentage and *d* as there may be an enhancement of visibility due to scattering of light as the concentration is increased.

Apparatus

The apparatus consists of a thin steel wire about 1 ft. long fixed at the upper end to a Vernier scale arrangement and at the lower end to a small thin circular metallic disc about 1 in. in diameter with a hole in the centre. The disc is coated with white enamel on which a circle is drawn with black ink. The black circular line with white enamel as the background serves as an excellent 'object' to be viewed. The Vernier scale arrangement is capable of two independent movements by means of two screws. One screw is adjusted till the disc just touches the surface of suspension. The Vernier scale then reads zero. The wire is then lowered gradually by working the second screw till the dark line becomes just invisible. The distance through which it has been lowered, is read by means of the Vernier scale arrangement accurate up to 1/10th of a mm.

Experimental

In order to find the relation between *d* and the clay content of a soil, varying concentrations (0·1, 0·2, 0·3, 0·4, 0·5, 0·6, 0·7, 0·8, 0·9 and 1·0 per cent) of a soil (Lab. No. P.C. 13) were prepared. As this soil contains 55 per cent of clay and as in the proposed method we shall prepare one per cent suspension, the above suspensions may be regarded as equivalent to 5·5, 11·0, 16·5, 22·0, 27·5, 33·0, 38·5, 44·0, 49·5 and 55·0 per cent of clay respectively in the original soil. The clay was separated in each case by pipetting 50 c.c. of the suspension from 5 cm. depth after allowing the appropriate time of settling. This volume was then diluted to 500 c.c., put into a fairly wide cylinder, shaken and the disc lowered into it. The values of *d*, determined in this way, are given in Table I against the clay percentage of the suspensions. These values when plotted would give a smooth curve which can serve as the basic curve for all clay determinations.

Table I

Relation between clay percentage and distance (d) *through which the object is lowered*

Clay percentage	*d* (cm.)
5·5	14·22
11·0	8·40
16·5	4·54
22·0	3·83
27·5	3·26
33·0	2·90
38·5	2·82
44·0	2·76
49·5	2·72
55·0	2·66

In order to determine clay contents of soils one per cent suspensions are prepared, clay separated and diluted in the above manner and values of *d* determined in all cases. The percentage of clay is read from the basic curve corresponding to the value of *d* determined in each case. Clay contents of 100 soil samples were determined by the pipette method as well as by the proposed method. In Table II are recorded the differences between the values

given by the pipette method and the proposed method against the number of soils showing that difference. It will be seen that the proposed method compares very well with the standard pipette method and could be adopted in field laboratories. Precautions such as lowering the disc in the middle of the cylinder, using similar types of cylinders, keeping the eye always, as far as possible, at fixed distance above the suspension, would suggest themselves.

Table II

Comparison of the proposed method with the standard pipette method

Difference between percentages found by two methods	Number of soils showing the difference
3	9
2	17
1	40
0·5 and less	34

Sources of error and their discussion

Soils with high clay contents. It would appear from Table I that where soils rich in clay are concerned, the method becomes less sensitive. It has been found, however, by experience that the point at which the 'object' becomes invisible in such cases is very sharp and d can be determined with a greater degree of precision. If desired, the method may be modified in this way that when d determined in the case of a soil, corresponds to more than, say, 35-40 per cent of clay, then the diluted suspension may be further diluted with an equal volume of water and the value of clay determined for this suspension may be multiplied with two. Or in the alternative if a soil is considered at the outset to contain more than 35-40 per cent of clay then 0·5 per cent of the suspension may be prepared initially instead of 1 per cent or, 25 c.c. of the clay may be pipetted instead of 50 c.c. from 1 per cent suspension and diluted to 500 c.c. The values determined in such cases from the curve will have to be multiplied by 2.

In Table III results of clay contents of soils, containing above 40 per cent of clay, as determined by the original method as well as by the three modifications suggested above are given and compared with those obtained by the usual pipette method. The agreement is fairly close and it appears that in some cases even no modification is needed.

Variations in the intensity of light. It was felt that the variations in intensities of light at different times and in different places may affect

Table III

Comparison of clay centents by different modifications

Soil No.	Clay percentage				
	Original method	I Modification	II Modification	III Modification	Pipette method
P.C. 13	57·0	53·6	54·0	55·0	55·0
P.C. 123	..	74·6	75·8	72·8	79·7
P.C. 145	43·6	39·5	39·8	38·5	41·2
P.C. 146	42·5	39·6	44·0	43·6	44·0
P.C. 147	..	60·8	61·5	63·4	62·0
P.C. 141	54·0	48·6	46·0	46·8	47·5
P.C. 148	55·0	50·2	50·9	51·7	48·1

the values of d, thereby introducing errors in estimations of clay contents. In order to get a rough comparison of the intensities of light, a special apparatus, consisting essentially of a small metallic box with two slits having independent shutters on either side was devised. Small pieces of P.O.P. papers were inserted in each of the two apertures by temporarily sliding the shutters on the back side. One piece was exposed directly to sunlight by sliding one of the front shutters for 15 seconds. The tanning acquired by this served as a standard. The second piece was then exposed to the light whose intensity was required. The time which this paper took to acquire the same tanning was noted. The 'standard' paper alongside was occasionally viewed by moving the shutter for a second or so for the purpose of comparison. It may be mentioned that as P.O.P. papers are not sensitive to any appreciable degree in the diffused light, occasional exposures of the 'standard' papers for a second or two in the diffused light of the room would not affect its tanning previously acquired on exposure to sunlight. In this way by determining the time of exposure needed in different lights to get standard tanning on P.O.P. papers, their intensities were compared. This, though no doubt a rough method, served to give some idea of the intensities of light.

The basic curve between d and clay percentage (Table I) was determined in light whose intensity corresponded to 15 minutes' exposure. Observations were then taken with the same concentrations of P.C. 13 soil in six different places where times of exposure needed were 4, 6, 18, 62, and 77 minutes. The values for clay as determined with reference to the basic curve, are given in Table IV.

TABLE IV

Effect of different intensities of light on clay content

Percentage of clay as plotted on the basic curve prepared in light of intensity corresponding to 15 minutes' exposure	Percentage of clay as determined in lights corresponding to the following times of exposures					
	4 min.	6 min.	8 min.	34 min.	62 min.	77 min.
5·5	5·5	5·8	5·2	6·0	5·5	4·8
11·0	11·6	11·0	11·0	11·8	11·5	11·0
16·5	16·4	16·8	16·8	16·4	16·8	17·0
22·0	20·3	21·2	22·0	22·0	22·0	22·8
27·5	28·0	28·0	27·8	28·0	29·0	27·8
33·0	33·8	33·5	34·0	33·8	33·8	35·0
38·5	38·5	40·0	40·8	41·5	40·5	41·0
44·0	46·0	46·8	44·0	46·8	44·0	46·0
49·5	51·0	52·0	52·5	52·5	52·5	52·5
55·0	55·0	57·0	57·0	57·8	57·0	58·0

It will be seen that differences in the values of clay obtained by making observations in different intensities of light are very small except when clay contents are rather high but even for these the agreement is not so bad. But as in soils with high clay percentage, further dilution has been suggested and as extremes of intensities of light are to be avoided, the method is practically free from any serious error. In this connection the following points may be emphasized:

(*a*) The experiments should be conducted in diffused daylight in a room or otherwise covered place. In open space the glare of light reflected from the liquid interferes with the observations.

(*b*) The extremes of intensities of light should be avoided. For example, if the basic curve is prepared in light the intensity of which corresponds to 15 minutes' exposure, experiments should not be conducted in lights whose intensities correspond to more than 60 minutes or less than 3 minutes' exposures.

(*c*) It would be better to conduct determinations in the same room where readings for the preparations of the basic curve are taken.

Personal error. This can be eliminated if the basic curve is prepared by the observer himself. In Table V values obtained for 12 soils by two persons are given. The basic curve was prepared by one of them.

Different colours of soils. The colour of the suspension would appear at first sight to affect determinations by this method, but as the suspension is very dilute, the colour factor does not influence the results. In Table I soils selected were of all colours available. The agreement between clay contents as determined by the pipette method and the proposed method rules out any possibility of error on account of this factor.

TABLE V

Magnitude of personal error in clay estimation

Soil No.	Percentage of clay	
	Determined by A	Determined by B
P. C. 271	17·0	15·2
P. C. 230	27·0	24·6
P. C. 247	12·6	10·8
P. C. 255	14·6	13·0
P. C. 283	14·6	17·0
P. C. 285	16·6	18·2
P. C. 286	30·5	27·2
P. C. 287	20·2	20·5
P. C. 288	25·0	25·0
P. C. 290	12·8	10·5
P. C. 291	17·8	20·0
P. C. 292	23·5	22·5

SUMMARY

A simple method which can be easily adopted in field laboratories for finding clay contents of soils is described. It consists in measuring the turbidity of a diluted clay suspension with reference to standard suspensions by lowering gradually an object in the suspension till it becomes invisible to the eye placed vertically above the suspension at a convenient distance. Various sources of error are discussed.

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THE OCCURRENCE AND SIGNIFICANCE OF TRACE ELEMENTS IN RELATION TO SOIL DETERIORATION

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Certain elements, viz. boron, iron, manganese, etc. although present in soils in relatively small amounts are known to exercise a profound influence on the growth and yield of crops. Manganese occupies rather a conspicuous position among this class of elements and numerous studies of its roll in soils are described in literature. The classical work of Bertrand and Rosenblatt [1921] brought out that manganese is invariably present in plants and is essential for their normal development. McGeorge [1923] and Bertner [1935] had shown that if manganese is present in excess, to that sufficient for the normal growth of plants, it is known to have toxic effects.

Very little work had so far been done in India in connection with the occurrence of trace elements in soils. Quite recently Hoon, Dhawan and Madan [1941] examined soils from various districts of the Punjab for their trace elements content in relation to the yield of wheat. As a result of that investigation, significant correlations were shown to exist between the contents of manganese and available phosphates respectively in soils and the yield of wheat, but no significant correlation between the total soluble salt content and a low and insignificant correlation between the *p*H and yield of wheat were obtained. The present paper is intended to throw some fresh light on the occurrence and significance of manganese in the Punjab soils with special reference to soil deterioration.

Experimental

The method proposed by Iyer and Rajagopalan [1936] was adopted for the determination of manganese in soils. In the case of water samples a known volume was evaporated and the manganese determined in the residue. The *p*H of 1 : 5 soil suspensions and water samples was determined by the glass electrode according to Hoon and Taylor [1931]. The other analyses reported in this paper were done by the usual methods.

Soil profiles from areas with low water-table

The Punjab alluvium being relatively a recent formation a well-developed soil profile showing horizons of eluviation and illuviation, as characterize the soils of the hilly areas receiving high precipitation, is seldom met with. However, due to the arid climatic conditions prevailing in the Punjab, certain characteristics are developed which frequently influence structural or colour changes in the soil profile. Therefore in the absence of well-marked genetic horizons in the profile, soil samples were taken at known depths along the profile up to the water-table from a number of places and analysed for their manganese content. The results of the manganese content of a few soil profiles from areas with low water-table are given in Table I. It is brought out that manganese can be traced throughout the depth of the profile with slight but distinct accumulation in certain sections. This observation was at variance with those made by Kelley [1912] in connection with his study of the Hawaiain soils that the manganese content decreased from the surface downwards. It may be pointed out here that the manganese contents given in Table I are not of that high order reported by other investigators but as shown by Hoon, Dhawan and Madan [1941]. Manganese even in such amounts manifested a fairly significant and negative correlation with the yield of wheat in the Punjab. It was a matter for further study whether the effect of manganese on the yield of wheat was direct or indirect due to some other factor which determined the accumulation of manganese in the soil.

Manganese content of subsoil water samples

Pits were dug down to the water-table at a number of positions in certain reclamation areas, viz. Amirpura (125 acres), Maharanwala (13 acres), Chakanwali (3,400 acres waterlogged) and Raniwah Drain areas and samples of subsoil water taken from the bore-holes. These samples were analysed for their total soluble salt and manganese contents and *p*H. The results of analyses given in Table II show that the subsoil water samples taken from a number of sites in the same area manifest considerable differences in their soluble salts and manganese contents. It means that the subsoil flow in the Punjab alluvium is considerably impeded. However, a high soluble salt content of the water samples is invariably associated with a high manganese content. In areas where the water-table is within 3-4 ft.

TABLE I

Results of the manganese content of soil profiles taken from a low water-table area (Jhak Ditta Chak No. 433 G. B.)

Soil profile taken from Sq. No. 31/54			Soil profile taken from Sq. No. 56/47			Soil profile taken from Sq. No. 55/46 Field No. 1		
S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	S. No.	Depth	Manganese content in milliequivalens per 100 gm.t of soil
1	0—6 in.	3·85	1	0—6 in.	2·30	1	0—6 in.	3·70
2	6—12 in.	2·95	2	6—12 in.	2·40	2	6—12 in.	3·90
3	1—2 ft.	2·55	3	1—2 ft.	2·35	3	1—2 ft.	3·60
4	2—3 ft.	4·30	4	2—3 ft.	2·65	4	2—4 ft.	2·90
5	3—4 ft.	3·60	5	3—4 ft.	1·80	5	4—5 ft.	2·90
6	4—6 ft.	2·40	6	4—5 ft.	1·10	6	5—7 ft.	2·80
7	6—8 ft.	2·85	7	5—6 ft.	2·20	7	7—8 ft.	3·00
8	8—9 ft.	3·10	8	6—7 ft.	2·00	8	8—10 ft.	2·90
9	9—10 ft.	3·35	9	7—8 ft.	2·25	9	10—11 ft.	2·30
10	10—11 ft.	3·05	10	8—9 ft.	2·65	10	11—12 ft.	2·70
11	11—12 ft.	2·75	11	9—10 ft.	2·50	11	12—13 ft.	2·50
12	12—13 ft.	2·75	12	10—11 ft.	2·25	12	13—14 ft.	2·80
13	13—14 ft.	2·90	13	11—12 ft.	2·75	13	14—15 ft.	2·80
14	14—15 ft.	4·20	14	12—13 ft.	2·90	14	15—16 ft.	2·30
15	15—16 ft.	4·00	15	13—14 ft.	2·90	15	16—17 ft.	3·50
16	16—17 ft.	3·80	16	14—16 ft.	2·50	16	17—18 ft.	2·70
17	17—18 ft.	3·00	17	16—17 ft.	2·70	17	18—19 ft.	2·70
18	18—19 ft.	3·40	18	17—19 ft.	2·10	18	19—20 ft.	3·00
19	19—20 ft.	2·35	19	19—20 ft.	2·15	19	20—21 ft.	3·65
20	20—21 ft.	2·30	20	20—21 ft.	2·50	20	21—22 ft.	4·00
21	21—22 ft.	2·60	21	21—22 ft.	1·90	21	22—23 ft.	2·50
22	22—23 ft.	1·80	22	22—23 ft.	2·05	22	23—24 ft.	1·50
23	23—24 ft.	1·95	23	23—24 ft.	1·95	23	24—25 ft.	1·10
24	24—25 ft.	1·95	24	24—25 ft.	1·75			

from the surface the total soluble salt content of water is very low and there is little manganese in the subsoil water. This may be attributed to reduced impedence in the flow of water under high water-table conditions.

Manganese content of soils in relation to productivity

From the data of yield of major agricultural crops a few sites were roughly classed as good, average and poor. Soil samples were taken at those sites and a comparison of their manganese content made. The results of analyses are given in Table III. This study shows that there is relatively a higher manganese content in soils representing areas having poor yield of crops than those taken from areas with good or average yield. The difference in the manganese content is more pronounced in the top 3-4 ft. portion of the various soil profiles examined.

It is admitted that in case of soils representing poor crop yield the pH is definitely high and in certain cases the total soluble salt content is high and these might also contribute to low crop yield. It has been shown by Hoon and Dhawan [1940] that soils having high pH, if subjected to electrodialysis, yield more manganese in soluble form than soils of low pH. Moreover, the major portion of electrodialysable manganese separates in the beginning. It is not surprising, therefore, that in soils of high pH more manganese comes out in the soluble form and thus, becoming available to plants in quantities greater than their normal requirements, inhibits their growth. Further, this availability of manganese is reduced when the dominant base in the exchange complex of soil is calcium. Total soluble salts when present in high concentrations, as reported for certain cases in Table III, also affect the yield adversely. But, as pointed out by Hoon, Dhawan and Madan [1941], the correlation in the case of manganese was more significant than either of those of pH or total soluble salts in relation to the yield of wheat in the Punjab.

TABLE II

Results of analyses of subsoil water samples taken from different reclamation areas

S. No.	Name of site	pH	Parts per 100,000 parts of water: Total soluble salt content	Parts per 100,000 parts of water: Manganese content	Remarks
1	Amirpura reclamation site . . .	9·01	984·8	182	
2	Ditto	7·90	334·8	Traces	
3	Ditto	8·86	498·2	55	
4	Ditto	8·43	280·6	40	
5	Ditto	7·67	214·4	51	
6	Ditto	7·87	114·4	81	
7	Ditto	7·30	53·8	nil	
8	Ditto	7·14	76·6	nil	
9	Ditto	7·34	71·2	nil	
1	Mehranwala reclamation site . . .	8·12	532·2	66	
2	Ditto	7·18	208·2	18	
3	Ditto	7·35	292·2	30	
4	Ditto	7·92	2489·1	106	
5	Ditto	8·42	2279·6	105	
6	Ditto	7·85	363·6	62·6	
7	Ditto	8·22	149·8	22·6	
8	Ditto	7·64	766·4	72	
9	Ditto	7·56	312·0	32	
10	Ditto	8·34	135·9	16	
1	Lower Raniwali drain area	7·12	407·0	48	
2	Ditto	8·55	280·2	66	
3	Ditto	7·18	162·0	64	
4	Ditto	6·73	512·6	92	
5	Ditto	6·60	549·6	150	
1	Chakanwali reclamation farm . . .	7·38	38·5	nil	Waterlogged site (water-table within 3-4 ft. from surface)
2	Ditto	7·42	18·8	nil	Ditto
3	Lil Village on U.C. Canal . . .	7·32	27·30	nil	Ditto
4	Place near chichoki mallian . .	6·76	54·50	0·43	Ditto

During the course of the soil surveys it was observed that different types of naturally growing flora get established at various places. An examination of soils with reference to the type of flora borne on them had revealed that some types of flora, at any rate, might serve as indicators of the development of certain special characteristics in the soils [Hoon, Dhawan and Mehta, 1939; Hoon and Mehta, 1937]. As an illustration, one case of such typical flora may be cited. *Lani* (*Suaeda fruticosa*) grows profusely, to almost exclusion of all other types of natural flora, on land representing a fairly advanced stage of deterioration. Such land can be classed as uneconomic from the point of view of agricultural development or reclamation. With advancing deterioration such *lani*-bearing areas, in course of time, become devoid of all vegetation and develop into bare batches. Soil samples taken from areas bearing *lani* and devoid of vegetation were analysed for their manganese and total soluble salt contents and pH. The results of analyses are given in Table IV. It is shown that such areas have a high manganese content, soils representing areas devoid of vegetation having more manganese than those taken from *lani*-bearing areas. Another characteristic difference in the manganese content of soils from those two areas is that, whereas the manganese content in the top portions of the profiles representing *lani* is less than the underlying portions, that in profiles from areas devoid of vegetation is high throughout the whole profile. Incidentally again, the soils from these two types of

TABLE III

Results of analyses of soil samples with reference to the cropping condition at the sites

S. No.	Description of site, etc.	Depth of soil sample	Per cent total soluble salt content	pH	Manganese content in milliequivalents per 100 gm. of soil	Classification of land on the basis of productivity of major agricultural crops, i.e. good, average or poor
1	Field No. 3860 Mahrunwali	0—7 in.	0·11	7·98	0·75	Good
2		7—26 in	0·07	7·94	1·05	
3		26—44 in.	0·33	8·00	2·00	
4		44—50 in.	0·09	7·86	0·70	
1	Field No. 2130 Mahrunwali	0—6 in.	0·16	7·99	1·30	Good
2		6—12 in.	0·14	7·77	1·30	
3		12—24 in.	0·14	7·82	1·10	
4		24—36 in.	0·14	8·04	1·40	
1	Field No. 2710 Mahrunwali	0—3·5 in.	0·14	8·05	0·75	Average
2		3·5—21 in.	0·11	7·95	1·20	
3		21—42 in.	0·11	8·10	1·20	
4		42—53 in.	0·13	7·57	2·85	
5		53—64 in.	0·11	8·27	1·20	
1	Field No. 2710 Mahrunwali	0—¾in.	1·05	7·62	2·75	Below average
2		¾—5 in.	1·11	8·40	2·75	
3		5—27 in.	1·00	8·53	4·30	
4		27—46·5 in.	0·17	8·44	1·90	
5		46·5—55 in.	0·25	9·58	2·80	
6		55—74 in.	0·20	8·85	2·30	
1	Plot 20 Ajudhiapur	0—6 in.	1·69	10·46	4·00	Poor
2		6—12 in.	1·35	10·44	4·00	
3		12—24 in.	1·00	10·40	3·40	
4		24—36 in.	0·66	10·28	2·70	
1	Plot 9 Ajudhiapur	0—6 in.	0·18	9·47	3·90	Poor
2		6—12 in.	0·10	8·60	4·90	
3		12—24 in.	1·09	9·28	4·90	
4		24—36 in.	0·59	9·84	4·05	
1	Rakh Amanat Sarai (Thur Area)	0—3 in.	..	9·60	4·35	Poor
2		3—6 in.	..	9·80	4·55	
3		6—13 in.	..	10·20	4·60	
4		13—32 in.	..	9·90	4·70	
1	Amirpura Field No. 446 Bl.	0—6 in.	..	9·56	4·10	Poor
2		6—12 in.	..	10·10	4·55	
3		12—24 in.	..	10·02	5·25	
4		24—36 in.	..	9·97	4·35	

areas have a very high pH which confirms the statement made in the earlier part of this paper and in a previous publication [Hoon and Dhawan, 1940].

Manganese content of soils in relation to their mechanical composition

An accumulation of manganese in certain sections of the soil profiles occurs as pointed out in preceding sections. Robinson [1929] showed that manganese occurred in soils largely as manganese dioxide concretions concentrated in the sand and silt fractions and the bulk of exchangeable manganese was located in the colloidal fractions. An examination was made to bring out if the accumulation of manganese in the soils under reference manifested any relation to their mechanical composition. Although it was not possible to determine the proportion of manganese in the form of concretions and exchangeable separately, as reported by Robinson, but the results of the total manganese content and mechanical analysis

of soils are given in Table V. It is shown that, in general, an increase in the silt and clay fractions (particles below 0·02 mm.) is accompanied by an increase in the manganese content of soils and vice versa. It seems, therefore, that as far as the presence of manganese in the soils of the Punjab is concerned the major part occurs in the exchangeable form rather than as concretions concentrated in sand fraction. That also accounts for the comparatively low content of manganese reported for the Punjab soils than those reported by other investigators for some special manganiferous soils in other parts of the world.

TABLE IV

Results of analyses of soil samples from deteriorated areas

S. No.		Type	Depth	Per cent total soluble salt content	*p*H	Maganese content in milliequivalents per 100 gm. of soil
A	1	Profile taken from an area under *lani* (*Suaeda fruticosa*).	0—4 in.	2·46	9·76	2·15
	2		4—16 in.	0·19	10·15	3·25
	3		16—24 in.	0·13	9·87	2·00
	4		24—36 in.	0·11	9·64	4·00
B	1	Ditto	0—2½ in.	1·16	8·97	1·95
	2		2½—11 in.	0·57	9·48	4·40
	3		11—22 in.	0·53	9·41	3·00
	4		22—33 in.	1·15	9·11	3·20
	5		33—48 in.	0·83	9·24	3·20
C	1	Profile taken from an area devoid of vegetation	0—½ in.	0·13	9·07	4·05
	2		½—3½ in.	0·61	9·64	4·95
	3		3½—26 in.	0·51	9·82	5·10
	4		26—36 in.	0·23	9·64	4·60
D	1	Ditto	0—½ in.	0·84	9·28	3·20
	2		½—7 in.	1·18	9·70	4·40
	3		7—18 in.	0·99	9·79	3·70
	4		18—32 in.	0·61	10·90	4·00
	5		32—48 in.	0·43	10·00	3·60

The occurrence of kankar *(calcium carbonate : soil concretions) in the Punjab soils in relation to their manganese content*

On account of arid climatic conditions prevalent in the Punjab plains the soils of this part contain varying contents of soluble sodium salts, viz. sodium chloride, sodium sulphate, etc. and are alkaline in reaction. Moreover, at certain places and at certain depths of soil profile *kankar* (nodular calcium carbonate) is met with. The factors governing the formation of *kankar* in soils has not yet been precisely defined. A fluctuating water-table rich in bicarbonate content is considered to be one plausible explanation of the formation of *kankar* in soils [1936].

A few soil profiles from *kankar*-bearing areas were examined for their manganese content. The results of this study are given in Tables VI, VII and VIII. It is brought out that :

(*i*) The manganese content of the soil in the layer where *kankar* nodules are present is comparatively higher than in the layer where they are absent (Table VI).

(*ii*) There is a slight indication of the manganese content of the *kankar* nodules being generally higher than that in the soil present in the *kankar* strata (Table VII).

(*iii*) If the *kankar* nodules were graded according to their sizes, e.g. large, medium and small (pea-sized) then there is a slight indication of differences in the manganese content of *kankar* nodules according to their sizes, the manganese content of the pea-sized *kankar* nodules being relatively greater than that of the large or medium-sized nodules (Table VIII).

The accumulation of manganese in the *kankar* nodules may be attributed to the fact that the formation of *kankar* is associated with the high alkalinity of soil which condition is also conducive to a high manganese content. It is not

unlikely that manganese forms the nucleus for the nodules to grow in size due to the causes not yet clearly defined. This might, however, explain why the percentage of manganese in big-sized *kankar* nodules is comparatively less than in the pea-sized *kankar*.

TABLE V

Results of analyses of a few soil profiles showing the manganese content of soils in relation to their mechanical composition

S. No.	Depth	Mechanical analysis			Min. m.e. per 100 gm. of soil	pH
		Per cent sand	Per cent silt	Per cent clay		
Profile I						
1	0—6 in.	33·9	36·3	20·1	4·6	9·8
2	6—12 in.	43·2	32·0	13·7	3·2	9·6
3	1—2 ft.	51·0	27·0	14·3	2·6	9·7
4	2—3 ft.	42·6	34·0	15·1	3·5	9·5
5	3—4 ft.	47·2	26·0	17·8	2·8	9·1
6	4—5 ft.	60·6	17·9	10·5	2·8	9·7
7	5—6 ft.	56·1	25·7	9·3	3·9	9·4
8	6—7 ft.	62·8	22·2	8·7	2·8	9·6
9	7—8 ft.	39·8	34·9	14·0	4·1	9·5
10	8—9 ft.	60·3	25·1	6·7	2·6	9·5
11	9—10 ft.	76·0	34·3	6·7	3·3	9·5
12	10—11 ft.	66·9	18·6	8·0	2·8	9·4
13	11—12 ft.	79·4	11·9	5·4	2·2	9·2
14	12—13 ft.	79·4	12·9	5·9	2·9	8·7
Profile II						
1	0—6 in.	36·3	27·5	25·6	4·1	9·7
2	6—12 in.	50·6	21·1	17·7	3·2	9·6
3	1—2 ft.	51·9	20·5	16·3	3·5	9·6
4	2—4 ft.	35·5	41·2	15·1	4·1	8·9
5	4—5 ft.	55·7	21·0	13·5	3·5	9·5
6	5—6 in.	55·7	21·2	12·9	3·4	9·5
7	6—7 ft.	69·6	13·6	8·8	2·4	8·8
8	7—8 ft.	74·6	12·3	5·6	2·0	8·8
9	8—9 ft.	66·1	17·3	6·9	3·3	9·0
10	9—10 ft.	54·8	22·1	13·3	3·8	9·6
11	10—11 ft.	51·8	27·4	10·6	3·0	9·0
12	11—12 ft.	25·2	47·2	16·7	4·8	9·1
13	12—13 ft.	44·0	35·7	11·4	4·2	9·2
14	13—14 ft.	61·5	28·3	5·6	3·5	9·3
Profile III						
1	0—6 in.	62·7	19·5	8·1	2·3	9·9
2	6—12 in.	58·7	19·1	15·7	3·3	9·8
3	1—2 ft.	49·4	24·3	20·7	4·9	9·9
4	2—3 ft.	49·8	23·4	21·0	3·9	9·8
5	3—4 ft.	48·9	23·2	20·0	4·3	9·7
6	4—5 ft.	61·6	19·0	11·6	2·7	9·7
7	5—6 ft.	45·0	29·8	13·9	2·9	9·6
8	6—8 ft.	46·3	28·5	15·1	3·2	9·6
9	8—9 ft.	60·3	18·7	10·8	2·0	9·5
10	9—10 ft.	59·6	12·5	16·6	2·1	9·5
11	10—11 ft.	29·5	40·9	20·9	3·0	9·5
12	11—12 ft.	34·9	36·5	17·0	3·0	9·5
13	12—13 ft.	35·4	38·9	15·1	3·3	9·5
14	13—14 ft.	37·9	36·8	13·8	1·6	9·4
15	14—15 ft.	45·6	31·0	11·7	1·6	9·4
Profile IV						
1	0—2 in.	55·4	28·2	11·5	3·2	8·4
2	2—6 in.	66·7	17·4	8·1	2·4	8·4
3	6 in. —3 ft.	94·9	1·0	0·7	2·2	8·5

Table VI

Results of the manganese content of some kankar *bearing soil profiles*

S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	Characteristics of soil strata
Profile I			
1	0—6 in. .	2·1	
2	6 in.—1 ft. .	3·5	
3	1—2 ft. .	3·6	
4	2—3 ft. .	3·7	
5	3—4 ft. .	3·7	
6	4—5 ft. .	3·6	*Kankar* zone having small-sized nodules
7	5—6 ft. .	3·9	
8	6—7 ft. .	3·9	
9	7—8 ft. .	3·2	
10	8—9 ft. .	3·5	
11	9—10 ft. .	2·1	
12	10—11 ft. .	3·0	
13	11—12 ft. .	2·7	
14	12—13 ft. .	2·6	
15	13—14 ft. .	2·6	
16	14—15 ft. .	2·5	
17	15—16 ft. .	2·2	
Profile II			
1	0—6 in. .	2·2	
2	6 in.—1 ft. .	2·3	
3	1—2 ft. .	2·8	
4	2—3 ft. .	3·0	
5	3—4 ft. .	3·3	
6	4—5 ft. .	3·0	*Kankar* zone having small-sized nodules
7	5—6 ft. .	3·2	
8	6—7 ft. .	4·2	
9	7—8 ft. .	3·2	
10	8—9 ft. .	2·7	
11	9—10 ft. .	2·1	
12	10—11 ft. .	1·9	
13	11—12 ft. .	2·1	
14	12—13 ft. .	2·0	
15	13—14 ft. .	1·0	Almost sand
16	14—15 ft. .	1·8	Coarse sand saturated with subsoil water
17	15—16 ft. .	1·9	
18	16—17 ft. .	2·0	
Profile III			
1	0—6 in. .	2·0	
2	6 in.—1 ft.	3·1	
3	1—2 ft. .	3·0	
4	2—3 ft. .	3·6	
5	3—4 ft. .	3·6	
6	4—5 ft. .	3·4	*Kankar* zone having small and big-sized *kankars*
7	5—6 ft. .	3·2	
8	6—7 ft. .	3·7	
9	7—8 ft. .	2 9	
10	8—9 ft. .	3·4	
11	9—10 ft. .	2·4	
12	10—11 ft. .	2·8	Fine sand
13	11—12 ft. .	2·7	Coarse sand
14	12—13 ft. .	2·7	Coarse sand
15	13—14 ft. .	1·9	Sand saturated with sub-soil water
16	14—15 ft. .	1·8	
17	15—16 ft. .	1·4	
18	16—17 ft. .	1·6	

Summary

Manganese has been shown to be present in the soil profile right up to the water-table with slight accumulation in certain sections of the profile in areas where the water-table is low. In general an increase in the silt and clay fractions is accompanied by a slight increase in the manganese content of soil and vice versa.

Table VII

Results of the manganese content of kankar *nodules and the soil matrix in some* kankar *bearing soil profiles*

S. No.	Site	Depth	Manganese content m.e. per 100 gm.	
			Kankar nodules	Soil matrix in that strata
Profile I	Chakanwali Reclamation area C/1 plot			
1		0—7 in.	2·8	2·5
2		7—12 in.	4·1	2·8
3		1—2 ft.	2·8	2·6
4		Below 2 ft.	2·9	2·7
Profile II	Do. X/1 plot			
1		0—8 in.	4·8	2·0
2		8—17 in.	3·5	2·5
3		17—28 in.	2·6	1·9
4		28—36 in.	2·6	2·0
Profile III	Do.			
1		0—10 in.	5·2	1·9
2		10 in.—2 ft.	5·4	3·8
3		2—3 ft.	3·4	3·2

Table VIII

Results of manganese content of the different sizes of kankar *nodules and the soil matrix in* kankar *bearing strata of various soil profiles*

S. No.	Manganese content milliequivalents per 100 gm.			
	Soil matrix	Big-sized nodules	Medium-sized nodules	Small-sized nodules
1	3·5	3·0	3·6	5·0
2	2·8	Not present	Not present	37·0
3	2·9	Do.	5·8	7·2
4	3·9	3·6	4·2	8·0
5	4·0	Not present	4·4	4·6
6	4·15	4·0	4·6	6·2
7	3·4	3·6	Not present	4·0
8	3·7	7·5	9·5	13·0
9	3·6	Not present	8·8	11·2

The subsoil water samples from areas having low crop yields have usually higher soluble salt and manganese contents than those from good or average land. Likewise, the soils from the former type of land have comparatively greater manganese content than those from the latter types, the difference being more prominent in the top 4 ft. portion of the profile.

Soils of high pH value are associated with relatively greater manganese content than those with low pH.

A number of soils and subsoil water samples have been analysed for their total manganese content. A qualitative relationship is brought out between the manganese content and fertility of the soils, i.e. good and average soils contain less manganese than bad ones.

The small (pea-sized) *kankar* nodules have a slightly higher manganese content than large or

medium-sized nodules. The soil-matrix in the *kankar*-bearing strata has also slightly higher manganese content than soils in strata where *kankar* is absent.

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PRELIMINARY TREATMENT OF RED SOIL SEPARATES, AS OBTAINED BY MECHANICAL ANALYSIS FOR MINERALOGICAL EXAMINATION

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In course of mineralogical analysis of Indian red soils by petrographic methods, it was observed that soil fractions of different sizes, as obtained by mechanical analysis were more or less red in colour due to adhering iron oxide, which made identification of these soil separates difficult. The fine sand fractions appeared in many cases to consist entirely of iron oxide, although in reality they were composed of diverse minerals with coating of iron oxide hydrated or non-hydrated. Thus the removal of materials which form coating over the minerals is essential before the minerals can exhibit fully their individual optical properties.

Hendrick and Newland [1928] suggested treatment of soil separates with oxalic acid for removal of iron oxide stains. Tamm [1934] advocated use of ammonium oxalate for the same purpose. But it has been observed that even long continued boiling with oxalic acid or ammonium oxalate does not completely remove iron oxide coating in many cases. The use of acid ammonium oxalate is not entirely satisfactory, inasmuch as it takes unduly long time tending to act upon other soil constituents. Truog and others [1936] have fully elucidated the necessity of removal of such interfering materials and have devised a special treatment of soils for mechanical and mineralogical analysis. The sodium sulphide-oxalic acid treatment which they adopted is not free from objections. It requires a long time to be carried out and may attack less resistant materials in soils. In spite of some of its defects the above treatment is an essential supplement to the processes involved in mechanical analysis of soils.

The author has made use of hydriodic acid for removal of adhering free iron oxide and free alumina to the mineral particles in different fractions of red soils obtained by mechanical analysis in which sulphide-oxalic acid treatment has not been included. A perfectly white residue is obtained by keeping the soil separates (1 gm. in 25 c.c. of 10 per cent acid) for two hours on a water bath. The residue may be filtered and washed with water until free from coloured solution of iron oxide in the acid. If the material is not perfectly white by one treatment it should be subjected to a second operation in the same way as the first one. It has been seen that alumina is less easily acted on by this reagent than free iron oxide. Hydriodic acid does not appreciably attack soil constituents other than free iron oxide and free alumina.

A method of estimation of free iron oxide and free alumina in red soils has been found possible by using hydriodic acid. A treatment with this reagent in course of mechanical analysis of soils by alkaline permanganate method evolved by the author [Chakraborty, 1935] seems advisable. These points will form themes of future publication. This reagent may also find useful application in analysis of clays by X-ray.

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STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

IX. THE INTERRELATION OF MANURIAL FACTORS AND WATER-SUPPLY ON THE GROWTH AND YIELD OF 4-F COTTON ON LIGHT SANDY SOILS*

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(With five text-figures)

Introduction

The investigations described here had their origin in the discovery of the causes responsible for the bad opening of bolls in the Punjab-American cottons, a phenomenon popularly termed as *tirak*. It has been established that two types of soil conditions are mainly associated with *tirak*. The present studies are in relation to only one of the soil types, namely light sandy soils deficient in nutrients, especially nitrogen.

The growth of plants on such soils is normal in the earlier stages of development and the appearance of deficiency symptoms usually synchronizes with the approach of the reproductive phase. At this stage, the stems of the plants are characterized by the presence of anthocyanin pigments. There is also yellowing of leaves, followed in time by reddening and premature defoliation which intensifies with age. A marked reduction in the number and size of bolls occurs, eventually culminating in poor yields. As a decrease in boll size is accompanied by immaturity of seeds and poor quality of lint, the loss is both quantitative and qualitative.

Premature yellowing of leaves indicates internal starvation for want of one of the essential elements, such as nitrogen, phosphorus, or potassium. Such deficiency symptoms in leaves have been described by various workers in case of other crops as well. Immaturity of seeds in the bolls showing *tirak* further suggests the probability of potash deficiency. From various parts of America, the cotton plant has been reported to show immaturity of seeds when grown on potash-hungry soils.

If these symptoms were directly caused by the deficiency of any one of the essential elements, application of the same should normally prevent the development of such abnormalities, while the use of others would prove ineffective (Liebig's law of the minimum). The effectiveness of one factor may, however, be limited by the level of another factor or factors (the principle of limiting factors). Hence it was necessary to study simultaneous changes in the level of all the three elements (N, P, K) by laying out multiple-factor experiments. For the same reason, the possibility of other factors, such as water-supply and organic manure, modifying the response to any one of the above-mentioned nutrients could not be ignored.

It is not possible to appreciate and understand fully the effects of treatments, if the study is confined to the final yield data alone. Yield is the integration of growth processes and success or failure of any treatment would figure in the developmental records, collected at the different stages of growth. Morphological development is the index of the progress of physiological processes and the influence of disturbing factors, local or general, would appear as depressions or peaks in the normal trend of the curves. By growth-analysis, the nature of the events that lead up to the final yield, can be followed up. Additional information becomes available concerning the shape and form of growth curves. Clearly, therefore, it was important to undertake developmental studies to complete the picture in the present case.

Briefly stated, three features characterize the present investigation. Firstly, the studies have been made in relation to the problem of *tirak*, under known conditions of soil associated with it. Secondly, attention has been paid to the exploration of interactions by laying out factorial designs on modern lines. Thirdly, the studies have been supplemented by the maintenance of developmental records that have provided material for growth analysis.

No published data concerning the effects of fertilizers on the growth, development and yield of cotton, under known conditions of soil are available for the Punjab. A number of replicated single-factor yield trials were, all the same, made by the Department of Agriculture, Punjab [1936],

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Three conclusions emerge from the study of the results of these experiments. Firstly, the effect of nitrogen varied from place to place and season to season. In certain cases, the response was large, in others, meagre. Secondly, application at fruiting, in general, proved better than the one made earlier. According to Crowther [1938] the superiority of the later application is to be attributed to the sandy character of the Punjab soils and to local factors like early shedding of flowers caused by the nondehiscence of anthers. Thirdly, the phosphatic and the potassic fertilizers proved ineffective. Afzal [1941] also refers to the absence of any manurial responses to N, P or K in his experiments at Lyallpur, running consecutively for a period of five years. On the other hand, Crowther [1939] deplored the general apathy in India towards the use of artificials in view of the lower nitrogen content of the soils of this country in comparison with those of Egypt where nitrogenous fertilizers have, in particular, gained great popularity, and increasing returns have invariably been obtained. Recent researches done in the Punjab [Dastur, 1941; Dastur and Singh, 1942] have disclosed the causes for such discrepancies in the effectiveness of nitrogen. It is established that nitrogenous applications produce little effect on soils with saline subsoils. Heavy increases in yield are a feature of the light sandy soils having no subsoil salinity as would be clear from the results presented here. Relative proportions of the two soil types in a particular field would, therefore, determine the magnitude of its responsiveness.

Recently much useful work has been done in Sudan [Gregory *et al.* 1932; Crowther, 1934; Lambert and Crowther, 1935] and in Egypt [Crowther and his associates, 1935-1937] on the interactions of factors on crop growth. It may, however, be pointed out that these comprehensive experiments were laid out irrespective of the soil conditions. The rôle of soil as a master factor modifying the response to nitrogen, under the same climatic conditions, has already been quoted as an instance, and this point should not be lost sight of in comparing the results obtained in Egypt and Sudan with those reported herein.

Investigation

Experiment I (1937-38)

A piece of land, covering an area of 6 acres at the Lyallpur Agricultural Farm, where *tirak* symptoms were observed in 1935-36, was selected for this investigation. The soil of this area is light sandy composed of 10-15 per cent clay, 10-20 per cent silt and 65-75 per cent sand fractions. The land was kept fallow and given adequate preliminary cultivation during 1936-37, and was laid out in the succeeding season.

Description of the experiment

Experimental treatments and layout. The entire area was divided into three 2-acre blocks. Each block was subdivided into four main plots to which were assigned at random the four main plot treatments:

$$\binom{o}{m} \times \binom{w_1}{w_2} = w_1o,\ w_2o,\ w_1m,\ w_2m\,;$$

where o = No organic manure,
m = Farmyard manure at 5 tons per acre,
w_1 = Normal waterings during the growing season, and
w_2 = Heavy waterings during the growing season.

Differentiation of watering started from the first irrigation and was secured by rewatering w_2 plots at an interval of 16-24 hours following the normal course of watering throughout.

Each of the 12 main plots was split up into eight sub-plots for the random distribution of the eight treatment combinations enumerated below:

$$\binom{o}{n} \times \binom{o}{p} \times \binom{o}{k} = o,\ n,\ p,\ k,\ np,\ nk,\ pk,\ npk\,;$$

where o = No fertilizer,
n = Nitrogen at 48 lb. per acre,
p = P_2O_5 at 120 lb. per acre,
k = K_2O at 48 lb. per acre,
np = 48 lb. N + 120 lb. P_2O_5 per acre,
nk = 48 lb. N + 48 lb. K_2O per acre,
pk = 120 lb. P_2O_5 + 48 lb. K_2O per acre, and
npk = 48 lb. N + 120 lb. P_2O_5 + 48 lb. K_2O per acre.

N : P_2O_5 : K_2O : : 2 : 5 : 2

There were thus 32 treatment combinations with three absolute replicates. The total number of plots under experiment was 96, each of 1/20 acre at sowing, intercepted by buffer strips (4 ft. wide) as a provision against seepage effects.

Sowings were done from 18 to 22 May. Other cultural details were in conformity with the standard agricultural practices prevalent at the Lyallpur Farm.

Farmyard manure, superphosphate and potash were applied before the sowing irrigation. Ammonium sulphate at 100 lb. per acre was also given before sowing. The complementary dose of this fertilizer at 133 lb. per acre was given on 9-10 August.

Collection of data

Fortnightly height measurements and nodal counts of the main axis were taken on five plants in each plot. Cotyledonary node was reckoned as the zero node for counts and served as the lower fixed point for height. The point of attachment to main axis of the last leaf unfolded marked the upper point. The records for height and nodes

allowed of the calculation of the average internodal length.

Twenty plants, to form two units of ten plants each, were tagged in each subplot for determinations of the number of bolls and the weight of *kapas* per boll prior to each picking. These characters are the components of yield. The yield of *kapas* from each experimental plot, 1/48 acre each after rejecting non-experimental borders, was recorded for each picking. The cotton sticks from the experimental beds were weighed at harvest.

Experimental results

Height, node number and internodal length. The data for height, node number and internodal length have been graphically represented in Fig. 1. As potash had no effect on any of these characters the generalized values of o, n, p and np alone have been depicted.

The performance of the four groups of treatments, averaged over both levels of organic manure and potash is shown in Figs. 1A and 1B, under w_1 and w_2 separately. The salient features of these curves are summarized below.

The curves for height swing into characteristic S-shape. They rise slowly at first, followed by a rapid increase in elongation up till the 5th stage when a gradual deceleration sets in. The curves run together in the initial stages and widen with time. The ultimate trends are not discernible till the 4th stage is reached. Finally, they fall in the order $np>n>p>o$ under either type of waterings, but the differences are of a much higher order under heavy waterings. This indicates interaction of watering with nitrogen. The general level of curves for w_2 is higher than that for w_1. The effect of nitrogen and phosphorus are additive under w_1 as well as w_2. Thus there is little evidence of interaction of N with P or of watering with N×P.

The curves for node number rise rapidly to start with, sharply deflecting at the 3rd stage. The decelerated rate is, however, maintained over a long period. Curves tend to be parabolic in form with concavity towards the axis of abscissa. There are little differences in number of nodes due to manures at any stage in w_1. There is an indication of an appreciable increase under w_2.

The internodal length reveals a steep rise up to the 4th stage after which extension growth slows down rather rapidly with time. Node production, on the other hand, is kept up to a fairly later stage. In fact, there is a tendency for a fall in the internodal length towards maturity. This is due to continued meristematic activity of plants, though at a much slower rate, in the later stages. The curves for height take a resultant course.

The effect of nitrogen on the internodal length is specially marked with w_2 and starts quite early. The differences magnify with time. The effect of phosphorus (in the absence of nitrogen) is scarcely visible under w_1, and is of a much lower order, as compared with the effect of nitrogen, under w_2 as well. The influence on the elongation of internodes is maximum in case of np, with either type of watering.

The data rearranged for o, n, p, and np in the absence and in the presence of organic manure are plotted for the same characters in Figs. 1C and 1D respectively. The effect of p on height in absence of organic manure (Fig. 1c) is as marked as that of n while np causes but little further improvement. In the presence of organic manure (Fig. 1D) n continues to increase the height while p apparently depresses it. Furthermore, there is an indication of a continued increase due to np over that of n alone. In the presence of organic manure, therefore, any apparent increase due to phosphorus in the presence of nitrogen (np-n) is counterbalanced by a corresponding decrease due to phosphorus in the absence of nitrogen (p-o). On the other hand, there is a definite increase, as already mentioned, by phosphorus in the absence of organic manure. This brings out clearly the interaction M×P, but the differential behaviour of this interaction with nitrogen depicts N×M×P also. There is evidence of a real and marked effect due to phosphorus in the absence of both organic manure and nitrogen.

The above effects are not shown so well on node-number but are again conspicuous on the internodal length. This means that the treatment differences in height are mostly contributed by effects on the internodal length.

Boll number, boll weight and yield. The records for yield characters, collected plot by plot during the picking season, were properly compiled and statistically analysed (Table I). The mean squares for the different components, with the ratios they bear to the error variance are stated for the significant or the suggestive effects only.

The magnitude and the direction of effects are shown in the summary tables (II—V) showing all the main effects and their significant interactions, with appropriate standard errors.

A study of Table II reveals that watering has improved the size of bolls but not their number. The magnitude of increase is also the greatest of all the factors, though it is also subject to larger errors. Limitation of the design, however, is responsible for the non-significance of the effects of water on yield. For the same reason, the average influence of organic manure is not demonstrable on any of the characters in this experiment. Nitrogen is the most potent factor in-asmuch as improvement is twofold. The response is well pronounced on both the number and the size of bolls and collective effect appears on yield.

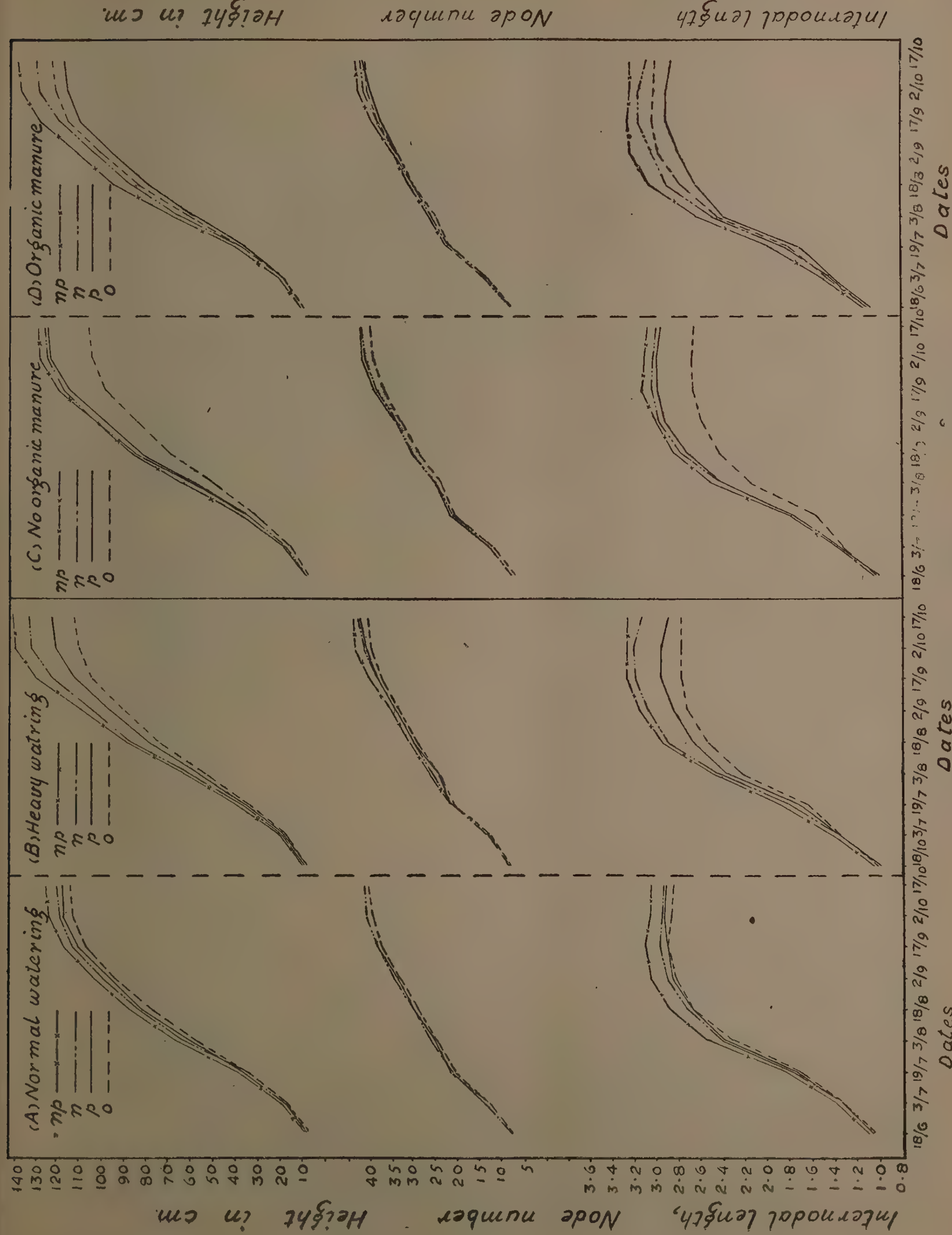

FIG. 1. Treatment effects on height, node number and internodal length

TABLE I

Analysis of variance

Experiment I

Due to	D. F.	Boll number: Mean square	Boll number: F	Boll weight: Mean square	Boll weight: F	Yield of *kapas*: Mean square	Yield of *kapas*: F
Blocks	2	144,968		0·0096		24,701·23	
W	1	48,801		1·6744	6·52*	13,585·04	
M	1	60,741		0·0478		6,080·17	
W × M	1	38,960		0·0171		888·17	
Error (a)	6	25,891		0·2569		10,333·0624	
Main plots	11						
N	1	171,781	13·04**	0·3545	10·97**	207,762·05	39·53**
P	1	10,576		0·1088	3·37	20,358·38	3·87
K	1	47,408	3·60	0·0110		51·04	
N × P	1	2,969		0·0006		2,420·04	
N × K	1	2,574		0·0732		77·04	
P × K	1	17,614		0·0019		1,457·04	
W × N	1	28,300	2·15	0·2516	7·78**	97,920·38	18·63**
W × P	1	7,093		0·0028		975·38	
W × K	1	3,597		0·0649		1,335·04	
M × N	1	12,789		0·1013		1,472·67	
M × P	1	54,506	4·14*	0·1088	3·37	35,882·67	6·83*
M × K	1	571		0·2707	8·38**	73·50	
N × P × K	1	2,235		0·0923		376·04	
W × N × P	1	29,975		0·0084		5,859·38	
W × N × K	1	6,568		0·0215		1,962·04	
W × P × K	1	1,722		0·0095		570·38	
M × N × P	1	1,307		0·3080	9·53**	45,414·00	8·64*
M × N × K	1	24,639		0·0447		16,120·17	
M × P × K	1	23,342		0·0564		12,060·17	
W × M × N	1	7,240		0·0210		16,432·67	
W × M × P	1	6,019		0·0259		2,688·17	
W × M × K	1	5,229		0·0504		32·67	
3rd & 4th order interactions	6	7,972		0·0678		3,165·39	
Error (b)	56	13,167·52		0·032321		5,255·3303	
Between plots	95						

* Significant at 5 per cent level ** Significant at 1 per cent level

TABLE II

Main effects

—		Number of bolls per plant: Actual	Number of bolls per plant: Difference	Number of bolls per plant: ±. S. E.	Weight of seed cotton per boll in gm.: Actual	Weight of seed cotton per boll in gm.: Difference	Weight of seed cotton per boll in gm.: ± S. E.	Yield of *kapas* in md. per acre: Actual	Yield of *kapas* in md. per acre: Difference	Yield of *kapas* in md. per acre: ± S. E.
Watering	w_1	51·22	—3·19	±2·32	2·091	+0·186*	±0·073	20·55	+0·89	±0·778
	w_2	48·03			2·277			21·44		
Organic manure	*o*	47·85	+3·55	±2·32	2·200	—0·032	±0·073	20·70	+0·60	±0·778
	m	51·40			2·168			21·30		
Nitrogen	*o*	46·63	+5·98**	±1·66	2·141	+0·086**	±0·026	19·25	+3·49**	±0·555
	n	52·61			2·227			22·74		
Phosphorus	*o*	48·88	+1·49	±1·66	2·161	+0·046	±0·026	20·45	+1·09	±0·555
	p	50·37			2·207			21·54		
Potash	*o*	51·20	—3·15	±1·66	2·176	+0·016	±0·026	20·97	+0·06	±0·555
	k	48·05			2·192			21·03		

Next in importance is phospohrus, with low suggestive response, i.e. 1·09 md. per acre as compared with 3·49 for nitrogen. It appears phosphorus has operated through increase in boll size. This confirms results obtained by Crowther [1937]. Except for a suggestive decline in boll number, there is little effect of potash application.

TABLE III

Watering × nitrogen interactions

Boll number per plant			Boll weight (gm.)			Yield of *kapas* (md. per acre)		
	w_1	w_2		w_1	w_2		w_1	w_2
o	49·44	43·83	*o*	2·084	2·198	*o*	20·00	18·50
n	*53·00*	*52·24*	*n*	*2·097*	*2·356*	*n*	*21·09*	*24·39*
Diff. ±2·34 . . .	*+3·56*	*+8·41***	Diff. ±0·037 . .	*+0·013*	*+0·158***	Diff. ±0·785 . .	*+1·09*	*+5·89***
W × N . . .	2·43	±1·66	W × N . . .	0·072**	±0·026	W × N . . .	2·40**	±0·555

Interactions. The interrelation of watering and nitrogen is shown in Table III. There is distinct evidence that water enhances the utilization of nitrogen. The increase in boll weight due to nitrogen is highly significant under heavy irrigations while there is little effect with ordinary waterings. The effect on boll number also points to the same direction though the interaction value fails to attain significance. It thus appears at its best in yield. Only 1·09 md. per acre increase in yield by nitrogen is recorded under ordinary waterings and this is apparently caused by its beneficial effect on bearing alone. The effectiveness of nitrogen increases by simultaneous increase in water-supply and has expressed itself in raising the yield by 5·89 md. per acre through its influence on both the boll number and the boll weight. This interaction has materially contributed to the significance of the main effects of nitrogen and water. Omission of any one of the factors in this experiment would have lowered the magnitude of the response to the other.

The effect of phosphorus in the presence and the absence of organic manure is shown in Table IV. There is an appreciable increase in the boll number by phosphorus in the absence of organic manure and a slight decrease in its presence. This differential behaviour is responsible for the significant interaction of P with M.

Mention has already been made of the beneficial effect of phosphorus on boll size. On further analysis of the data, it is seen that this improvement is peculiar to phosphorus in the absence of the organic manure. The nature of the interaction on boll number and boll weight is, therefore, similar.

TABLES IV & V

Interaction effects of organic manure, phosphorus and nitrogen

TABLE IV

M × P interaction

	o	*m*
Boll number per plant		
o	45·42	52·34
p	*50·27*	*50·46*
Diff. ± 2·34 .	*+4·85**	*—1·88*
Interaction value	—3·36*	±1·66
Boll weight (gm.)		
o	2·152	2·168
p	*2·247*	*2·168*
Diff. ± 0·037 .	*+0·095**	..
Interaction value	—0·047	±0·026
Yield of* kapas *(md. per acre)		
. . . .	19·42	21·48
p	*21·97*	*21·11*
Diff. ±0·785 .	*+2·55***	*—0·37*
Interaction value	—1·46*	±0·555

TABLE V

M × N × P interaction

	o	*n*	*m*	*mn*
Boll number per plant				
o	42·59	48·25	48·41	56·28
p	*48·75*	*51·80*	*46·79*	*54·14*
Diff. ± 3·31 .	*+6·16*	*+3·55*	*—1·62*	*—2·14*
Interaction value	0·52	±1·66		
Boll weight (gm.)				
o	2·048	2·256	2·190	2·146
p	*2·219*	*2·275*	*2·106*	*2·230*
Diff. ±0·052 .	*+0·171***	*+0·019*	*—0·084*	*+0·084*
Interaction value .	0·080**	±0·026		
Yield of* kapas *(md. per acre)				
o	16·53	22·32	20·51	22·45
p	*21·08*	*22·86*	*18·89*	*23·34*
Diff. ±1·11 .	*+4·55***	*+0·54*	*—1·62*	*+0·89*
Interaction value :	1·63**	±0·555		

The interaction M$\times$P is even more glaring in case of yield. The effect of phosphorus is significant at 1 per cent level in the absence of organic manure, there being no effect in its presence.

The significance of M$\times$N$\times$P interaction necessitates the study of the effect of phosphorus under o, n, m, and mn, individually. These relations have been shown for the three characters in Table V. The effect of phosphorus on boll number is not significant under any of the four combinations of nitrogen and organic manure and M$\times$N$\times$P is insignificant. The effects on boll weight and yield are different. A significant increase due to phosphorus is conditioned by the absence of both organic manure and nitrogenous fertilizers.

Stem dry matter. Essentially the same relations as for height and yield were found to hold in case of stem dry matter.

Experiment II (1938-39)

In view of the results obtained during 1937-38, it was next necessary to repeat the experiment under similar conditions of soil but under intensive system of cropping. A piece of four acres was selected in the same square, under the rotation wheat—*toria*—cotton.

Description of the experiment

This experiment was similar to the one already described with minor changes. Organic manuring was omitted as a treatment. Early and late applications of nitrogen were included as separate factors. The treatments were all combinations of :—

	(o) / (n_l)	$\times$	(o) / (n_e)	$\times$	(o) / (p)	$\times$	(o) / (k)	$\times$	(w_1) / (w_2)
Doses	N at 50 lb. per acre given on 16-17 August		N at 50 lb. per acre		P_2O_5 at 100 lb. per acre		K_2O at 200 lb. per acre		Water (normal and heavy) as in Expt. I

Applied on 18-20 May before sowing

Nitrogen, phosphoric acid and potash were supplied in the same forms as in the first experiment.

The purpose of the experiment was to obtain equally precise information on all the important comparisons. It was also necessary to reduce the block size to increase precision by confounding. Therefore, an 8$\times$8 quasi-Latin square was adopted to enable the elimination of two-way systematic soil variations. The layout plan of the experiment is set out in Fig. 2.

There were 64 plots of 1/21·8 acre each (33 ft. $\times 60\frac{1}{2}$ ft.), separated by interstrips, 7 ft. wide. Sowings were done from 22 to 26 May.

FIG. 2

8$\times$8 Quasi-Latin square

2^2 Factorial Design on 4-F Cotton (Year 1938-39)

(Plan and yields in chhataks)

Confounded completely among rows $N_E \times P \times K$, $N_L \times K \times W$, $N_E \times N_L \times P \times W$

Rows								
1	w_2 127	$nekw_1$ 164	$nlpkw_2$ 189	pkw_1 105	$nenlkw_2$ 278	$nenlpw_1$ 171	$nepw_2$ 110	nlw_1 203
2	$nlkw_1$ 257	$nenlpkw_1$ 256	pw_1 148	$nlpw_2$ 271	new_1 205	$nepkw_2$ 158	$nenl\ w_2$ 206	kw_2 125
3	pkw_1 152	$nepw_2$ 248	$nl\ w_1$ 219	w_2 150	$nenl\ pw_1$ 216	$nenl\ kw_2$ 214	$nekw_1$ 206	$nl\ pkw_2$ 272
4	$nenl\ pkw_2$ 335	$nl\ kw_2$ 272	$nepkw_1$ 222	$nenl\ w_1$ 311	kw_1 122	pw_2 139	$nl\ pw_1$ 219	new_2 290
5	$nepw_1$ 223	pkw_2 142	$nenl\ kw_1$ 299	$nekw_2$ 236	$nlpkw_1$ 254	$nl\ w_2$ 254	w_1 133	$nenl\ pw_2$ 301
6	$nl\ pw_2$ 240	$nenl\ w_2$ 303	kw_2 141	$nlkw_1$ 242	$nepkw_2$ 258	new_1 190	$nenl\ pkw_1$ 286	pw_1 117
7	$nekw_2$ 276	w_1 131	$nenl\ pw_2$ 317	$nepw_1$ 261	$nl\ w_2$ 234	$nl\ pkw_1$ 156	pkw_2 166	$nenl\ kw_1$ 319
8	$nenl\ w_1$ 276	$nl\ pw_1$ 234	new_2 248	$nenl\ pkw_2$ 319	pw_2 173	kw_1 123	$nl\ kw_2$ 258	$nepkw_1$ 282
Columns	1	2	3	4	5	6	7	8

$N_E \times K \times W$, $N_L \times P \times W$ and $N_E \times N_L \times P \times K$ confounded completely among columns

Collection of data

There were 11 rows in each plot, out of which two at the borders were rejected as non-experimental. Of the nine inner rows, four were set apart for dry weight and flowering data, and the remaining five reserved for yield and observational records, viz. height and nodes, boll number and boll weight.

Except yield results which were based on the entire experimental areas of each plot(15 ft. × 48·4 ft. = 1/80 acre), the other data relate to observations taken on selected plants randomly distributed in each plot. The necessary particulars are given in Table VI.

TABLE VI

Type of observation	Interval between two stages	Date of first observation	Date of final observation	Size of sample	Remarks
Height and nodes . . .	14 days	27-28/6	31/10, 1/11	10 plants	Each spaced 3 ft. × 1½ ft
Fresh and dry weights of different parts except roots	14 days	29/6-2/7	19-22/10	5 ,,	First two samples before thinning comprised 30, 15 plants respectively.
Flower counts	Daily	1/9	30/10	6 ,,	Set bolls counted finally on these plants
Boll number and boll weight before each picking					*Kapas* samples ginned

These records enabled the computation of a good deal of derived data, e.g. internodal length, growth rates, distribution of dry matter in parts, setting percentage, ginning out-turn, etc.

Experimental results

The entire data collected and derived were analyzed statistically. The 'analysis of variances' for the values at the final stage in case of most of the characters are presented in Tables VII and VIII which form the basis for the reduction of data in the form of summary tables. Effects of N and water alone are discussed in the following pages. P and K and their interactions are ineffective and will not receive attention.

TABLE VII

Analyses of variances

Experiment II

Due to	D. F.	Height		Node number		Internodal length		Flower production	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Rows	7	303·32	3·25*	1·4146	1·03	0·2391	5·39**	22358	2·21
Columns	7	172·464	1·809	2·4375	1·78	0·0807	1·82	10437	1·03
Treatments	25	390·301	4·09**	8·8315	6·476**	0·0952	2·15*	57222	5·66**
W	1	2149·481	22·55**	17·2225	12·63**	0·7098	16·02**	7331	...
N_L	1	2012·644	21·11**	87·8906	64·45**	0·1936	4·37*	376229	37·25**
N_E	1	4403·981	46·34**	87·4225	64·10**	0·9900	22·35**	745416	73·81**
P	1	3·195	...	0·9025	...	0·0012	...	4675	...
K	1	41·441	...	1·3225	...	0·0060	...	47	...
W × N_L	1	8·925	...	0·1406	...	0·0072	...	468	...
W × N_E	1	92·881	...	0·0400	...	0·0506	...	5421	...
W × P	1	11·475	...	0·3600	...	0·0156	...	5384	...
W × K	1	72·462	...	...	...	0·0452	...	4241	...
N_L × N_E	1	313·732	3·29	12·7806	9·37**	0·0541	...	149479	14·80**
N_L × P	1	14·726	...	0·0056	...	0·0086	...	1492	...
N_L × K	1	72·462	...	4·9506	...	0·0016	...	17922	...
N_E × P	1	57·191	...	0·0100	...	0·0281	...	3408	...
N_E × K	1	0·375	...	1·0000	...	0·0030	...	10328	...
P × K	1	17·956	...	0·4225	...	0·0196	...	5987	...
High order interactions . .	10	48·461	...	0·6317	...	0·0245	...	9271	...
Error	24	95·309	...	1·3637	...	0·0443	...	10099	...

TABLE VIII

Analysis of variances

Experiment II

Due to	D. F.	Setting per cent.		Boll number		Boll weight		Yield of *kapas*	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Rows	7	61·80	5·35**	313·24	...	1·4267	16·80**	4576·57	4·72**
Columns	7	12·05	1·04	184·12	...	0·4292	5·05**	3790·79	3·91**
Treatments	25	14·92	1·29	1489·01	4·37**	0·4214	4·96**	6986·81	7·21**
W	1	12·60	...	299·51	...	2·1481	25·30**	4692·25	4·84*
N_L	1	35·70	3·09	19896·87	58·41**	3·3512	39·47**	90751·56	93·71**
N_E	1	90·25	7·81**	11871·46	34·85**	2·0075	23·65**	63504·00	65·57**
P	1	8·70	...	409·81	...	0·2156	...	81·00	...
K	1	35·40	3·06	2·91	...	0·0048	...	729·00	...
$W \times N_L$	1	28·36	2·45	1·39	...	0·0142	...	315·06	...
$W \times N_E$	1	1·44	...	298·21	...	0·5710	6·72*	256·00	...
$W \times P$	1	6·25	...	42·66	...	0·0023	...	240·25	...
$W \times K$	1	0·42	...	674·38	...	0·0099	...	400·00	...
$N_L \times N_E$	1	55·88	4·84*	566·74	...	0·7799	9·18**	8789·06	9·07**
$N_L \times P$	1	15·02	...	72·14	...	0·0686	...	333·06	...
$N_L \times K$	1	2·03	...	167·86	...	0·0326	...	945·56	...
$N_E \times P$	1	0·56	...	981·65	...	0·2019	...	30·25	...
$N_E \times K$	1	10·89	...	0·01	...	0·1028	...	961·00	...
$P \times K$	1	13·32	...	1001·33	...	0·1565	...	196·00	...
High order interactions	10	5·616	...	79·13	...	0·08682	...	244·62	...
Error	24	11·55	...	340·61	...	0·0849	...	968·43	...

Height, node number and internodal length. The results of the effects of treatments on these characters are arranged in Table IX. Nitrogen applied either before sowing or before flowering has significantly increased the height, node number and the internodal length of the main axis. The magnitude of increase in the final height is higher with the early application of nitrogen as compared with the later. This is to be attributed to greater elongation of the internodes under the early application. Either of the applications are equally effective for node development.

TABLE IX

Treatment effects on height, node number and the internodal length

(Mean height in cm. per plant)

Nitrogen, early and late

	o	n_l	Diff.
			±3·45
o	100·4	116·0	±15·64**
n_e	*121·4*	*128·2*	*+6·79*
Diff. ±3·45	+21·0**	+12·2**	—8·85/2

Interaction ±2·44 = —4·425

Nitrogen and watering

	o	n_e	n_l	n_e+n_l	Mean
w_1	97·7	113·4	109·6	122·3	110·7
w_2	*103·1*	*129·5*	*122·5*	*134·1*	*122·3*
Diff.	+5·4	+16·1**	+12·9**	+11·8*	+11·6**
S. Ed.	±4 48				±2·44

TABLE IX—*contd.*

Average number of nodes on the main axis

	o	n_l	Diff.		o	n_e	n	n_e+n_l	Mean
			±0·413						
o . .	36·9	40·1	+3·24**	w_1 . .	36·4	39·5	39·6	41·2	39·2
n_e . .	40·1	41·6	+1·45**	w_2 . .	37·4	40·7	40·7	42·0	40·2
Diff. ±0·413	+3·2**	+1·45**	—1·79/2	Diff. . .	+1·0	+1·2	+1·1	+0·8	+1·0**
Interaction ±0·292= —0·895**				S. Ed. .	±0·584				±0·292

Mean internodal length (cm.)

	o	n_l	Diff.		o	n_e	n_l	n_e+n_l	Mean
			±0·074						
o . .	2·71	2·89	+0·18*	w_1 . .	2·68	2·87	2·77	2·97	2·82
n_e . .	3·02	3·08	+0·06	w_2 . .	2·75	3·18	3·01	3·19	3·03
Diff. ±0·074	+0·31**	+0·19*	—0·12/2	Diff. . .	+0·07	+0·31**	+0·24*	+0·22*	+0·21**
Interaction ±0·053= —0·06				S. Ed. . .	±0·106				±0·053

A further increase in height has occurred when nitrogen applied before sowing is supplemented by an equivalent amount of later dressing. There is, however, a clear evidence of falling off in the effectiveness of the additional dose. The interaction $N_E \times N_L$ is on the verge of significance. This is in conformity with the law of diminishing utility. The interaction $N_E \times N_L$ is highly significant in case of node number but it is not so in the case of the internodal length.

Watering has an increasing effect in case of all the three characters at all levels of nitrogen. Therefore the mean response to watering is statistically significant. The effect of watering is to be attributed to an increase in the internodal length mainly, the effect on node number being much smaller.

It is noteworthy that both nitrogen and water stimulate elongation of the main axis, but the magnitude of increase is higher under nitrogen than under heavy watering. The effect of the former is relatively better marked on node production than on the internodal length. The converse is true of the effect of water. Moreover, the effect of water tends to vary with nitrogen. In the absence of nitrogen the increase due to water does not attain significance anywhere. In the presence of nitrogen greater response to water is evidenced in longer internodes and taller plants. There is not the slightest indication of the interaction of nitrogen with water in case of node number. Nitrogen does not depend for node production on water which, in turn, is more important for the enlargement phase of growth. Similar results were obtained by Crowther [1934] with the difference that interaction effects were more pronounced in his case. That can be attributed, at least in part, to the inclusion of a third level of light watering as a treatment in his experiment.

Maximum dry weight per plant. A study of Table X reveals that nitrogen has significantly increased the dry weight (dead leaves excluded). The increase is relatively greater with the early application than with the later. The early application has the advantage of time for making extra growth. The increase due to double dose (n_e+n_l) is maximum though it is not proportionate to the amount added.

The effect of heavy watering is also significant but the effect is much smaller in magnitude as compared with that of nitrogen. The main effect of water derives its significance from the appreciable increases by double watering in the presence of nitrogen, especially the early applications. The interaction (water × nitrogen) is, therefore, better marked here than in the case of height.

TABLE X

Treatment effects on maximum dry weight in gm. per plant

Nitrogen, early and late			
	o	n_l	Diff.
			±21
o . .	312·0	412·5	+100·5**
n_e . .	*446·6*	*465·9*	*+19·3*
Diff. ±21 .	+134·6**	+53·4*	—81·2/2
Interaction ±14·8= —40·6*			

Nitrogen and water					
	o	n_e	n_l	n_e+n_l	Mean
w_1 . .	312·5	415·3	402·6	433·0	390·8
w_2 . .	*311·6*	*478·0*	*422·4*	*498·9*	*427·7*
Diff. . .	—0·9	+62·7*	+19·8	65·9*	+36·9*
S. Ed. . .	±29·6				±14·8

TABLE XI

Treatment effects on the total number of flowers produced per plant

Nitrogen, early and late			
	o	n_l	Diff.
			±5·92
o . .	97·8	139·5	+41·7**
n_e . .	*149·8*	*159·3*	*+9·5*
Diff. ±5·92	+52·0**	+19·8**	—32·2/2
Interaction ±4·2 = —16·1**			

Nitrogen and water					
	o	n_e	n_l	n_e+n_l	Mean
w_1 . .	97·5	147·5	139·3	155·0	134·8
w_2 . .	*98·1*	*152·1*	*139·6*	*163·6*	*138·3*
Diff. . .	+0·6	+4·6	+0·3	+8·6	+3·5
S. Ed. . .	±8·37				±4·19

Flower production. Nitrogen whether applied early or late has increased the aggregate number of flowers (Table XI). The effect is similar to that on dry weight and final height. Further increase in flowering is caused when the early application is augmented by a late one but this increase is rather low. Watering alone or in combination with nitrogen has not influenced flower production.

TABLE XII

Treatment effects on setting percentage

Nitrogen, early and late			
	o	n_l	Diff.
			±1·201
o . .	31·7	31·3	—0·4
n_e . .	*32·2*	*35·5*	*+3·3***
Diff. ±1·201	+0·5	+4·2**	+3·7/2
Interaction ±0·849 = 1·85*			

Nitrogen and water					
	o	n_e	n_l	n_e+n_l	Mean
w_1 . .	30·7	31·0	31·2	36·2	32·3
w_2 . .	*32·7*	*33·4*	*31·5*	*34·9*	*33·1*
Diff. . .	+2·0	+2·4	+0·3	—1·3	+0·8
S. Ed. . .	±1·698				±0·849

Setting percentage. Setting percentage is affected differently by nitrogen (Table XII). Neither the early application by itself encourages the percentage success of flowers into bolls nor does the late one alone. The reaction to the combined dose is strikingly favourable. Thus the interaction between the two times of application is positive and significant. It seems, then, that not until the concentration of nitrogen within the plant is very high, is the setting percentage affected.

Boll number, boll weight and yield. A study of Table XIII reveals that nitrogen whether applied early or late stimulates reproductive development. The latter appears to be more effective than the former. The double dressing has exactly doubled the out-turn as compared with the control, but its efficiency per unit of nitrogen supplied is lower. Every lb. of nitrogen gives a return of 13·28, 15·17 and 10·63 lb. of *kapas* in case of the early, the late and the combined applications, respectively. The superiority of the late application in yield is in accord with previous experience in the Punjab, but the difference is not statistically significant. The interaction between the two times of application is of the type recorded for the vegetative characters.

Mention has already been made of the operation of $N_E \times N_L$ interaction in the other direction in case of setting percentage. This counteracts the negative significant interaction in flower production with the result that interaction effect is absent in boll number. On the other hand, the improvement in boll size is seen to decline with the addition of the supplementary dose, and thus negative $N_E \times N_L$ interactions reappears in yield.

The mean response to water on yield appears to be just a reflection of its significant effect on boll weight, since boll number is not influenced by this factor. Improvement in the quality of opening and yield due to water is relatively smaller in magnitude.

TABLE XIII

Treatment effects on boll number, boll weight and yield

Nitrogen, early and late				*Water and nitrogen*					
	o	n_l	Diff.		o	n_e	n_l	n_e+n_l	Mean
(Boll number per square yard)									
			±3·26						
o	51·87	72·48	+20·61**	w_1	51·37	66·66	72·97	80·61	67·90
n_e	*68·46*	*83·12*	*+14·66***	w_2	*52·37*	*70·27*	*71·98*	*85·63*	*70·06*
Diff. ±3·26	+16·59**	+10·64**	—5·95/2	Diff.	+1·00	+3·61	—0·99	+5·02	+2·16
Interaction ±2·307 = —2·97				S. Ed.	±4·61				±2·307
Weight of kapas *per boll*									
			±0·052						
o	1·781	2·120	+0·339**	w_1	1·632	2·020	1·992	2·147	1·948
n_e	*2·069*	*2·187*	*+0·118**	w_2	*1·931*	*2·117*	*2·249*	*2·227*	*2·131*
Diff. ±0·052	+0·288**	+0·067	—0·221/2	Diff.	+0·299**	+0·097	+0·257**	+0·080	+0·183**
Interaction ±0·036 = —0·110**				S. Ed.	±0·073				±0·036
			±1·031						
o	12·86	22·11	+9·25**	w_1	12·08	20·54	20·90	25·01	19·63
n_e	*20·96*	*25·82*	*+4·86***	w_2	*13·63*	*21·37*	*23·32*	*26·63*	*21·24*
Diff. ±1·031	+8·10**	+3·71**	—4·39/2	Diff.	+1·55	+0·83	+2·42	+1·62	+1·61*
Interaction ±0·729 = —2·19**				S. Ed.	±1·459				±0·729

One point is note-worthy in connection with the interrelation of water and nitrogen on boll weight and yield.

There is little evidence that heavy watering enhances the utilization of nitrogen even when applied late (effect of water under *o* with *nl*). This result is at variance with the one emanating from the previous experiment. Experiment I was conducted on a piece of land that lay fallow for full one year, during which period it received lot of preparatory tillage. Fresh applications of the nitrogenous fertilizer only augmented the recuperated natural resources. Thus, nitrogen depended, for its full effect, on water which acted as a limiting factor.

In the second experiment, the primary requirement was nitrogen as the cotton crop followed *toria* and *sarson* (*Brassica* sp.) which left little time for preliminary cultivation. The level of fertility was, therefore, low, due to greater intensity of cropping and the response to nitrogen was high and there was no further increase in yield by extra watering.

The percentage increases due to nitrogen and water over the basal treatments (control for nitrogen treatments and normal waterings for water effect) are given in Table XIV (*a*) for boll number, boll weight and the resulting yield, individually.

TABLE XIV

The relative contribution of boll weight and boll number to total increase in yield

	(*a*) *Percentage increases over basal treatment*				(*b*) *Percentage distribution of increase in* kapas *into components of yield*			
	Nitrogen			Water	Nitrogen			Water
	N_E	N_L	N_E+N_L	W_2	N_E	N_L	N_E+N_L	W_2
Boll number . . .	32·0	39·7	60·2	3·2	66·4	67·6	72·5	25·4
Boll weight . . .	*16·2*	*19·0*	*22·8*	*9·4*	*33·6*	*32·4*	*27·5*	*74·6*
Total .	48·2	58·7	83·0	12·6	100	100	100	100

These have been derived from the data presented in Table XIV and give a quantitative idea of the relative share of the two components in the total contribution to yield. It is seen that although nitrogen causes a substantial increase in boll size, it is relatively more important for bearing. Water mainly functions through improvement in boll weight though nitrogen is far superior to it quantitatively, in this respect even. The specific functions of water and nitrogen are further illustrated in Table XIV (*b*). The relative importance of single dose of nitrogen for bearing is double that for the quality of bolls, and it is still higher in the case of the double dose. As regards water, the position is reverse.

Ginning percentage. Summarized results of the effect of nitrogen and water on the proportion of lint to *kapas* are presented in Table XV. Nitrogen has significantly lowered the ginning percentage. The improvement in boll size through N is not shared equally by seed and lint. Seed weight seems to derive benefit rather than the

TABLE XV

Treatment effects on ginning percentage

	o	n_l	Diff.		*o*	n_e	n_l	n_e+n_l	Mean
			±0·389						
o . .	33·89	31·89	$-2·00^{**}$	w_1 . .	34·17	31·86	31·97	31·06	32·26
n . .	*32·09*	*31·01*	$-1·08^{*}$	w_2 . .	*33·62*	*31·91*	*32·21*	*30·96*	*32·17*
Diff: ±0·389	$-1·80^{**}$	$-0·88^{*}$	$+0·92/_2$	Diff: . .	−0·55	0·05	0·24	−0·10	−0·09
Interaction ±0·275 = +0·46				S. Ed. . .	±0·55				±0·275

lint weight. The depressing effect of nitrogen on ginning outturn appears to be linear within the range of doses used. Water does not influence ginning outturn either singly or in combination with nitrogen.

Correlation studies

The treatment effects on yield and the developmental characters discussed in the preceding pages suggested that various characters were correlated. Correlation coefficients between different pair of characters, were, therefore, worked out for the whole data as well as the different components, viz. rows, columns, treatments and error (Table XVI).

The treatment yields are highly correlated positively with vegetative growth as measured by height and dry weight, and with meristematic activity as given by flower or boll formation. Similarly treatment effects on boll weight are reflected in yield.

TABLE XVI

Correlation coefficients and their significance

—	*n*	Dry wt. and yield	Height and yield	Boll wt. and yield	Flowers and yield	Bolls and yield	Boll No. and boll wt.	Ginning per cent and boll wt.
Rows	6	0·8875**	0·964**	0·9463**	0·1248	—0·2747	—0·4323	—0·3266
Columns	6	0·8228*	0·8987**	0·9555**	0·3716	0·5481	0·6504	0·1476
† Effective treatments	6	0·9130**	0·8926**	0·9014**	0·954**	0·9807**	0·8252*	—0·8575**
‡ Ineffective treatments	17	0·5784**	0·3815	0·3974	0·4472	0·2528	—0·1146	0·5036*
Error	23	0·4872*	0·8439**	0·5905**	0·4535*	0·4927*	0·1667	0·0492
Total	62	0·8024**	0·8748**	0·8107**	0·7218**	0·7330**	0·3890**	—0·3423**

† Pertaining to nitrogen and water factors, i.e. 8 treatment combinations
‡ Pertaining to phosphorus and potash and all their interactions

The correlations between yield and height, yield and dry weight, and yield and boll weight are also highly significant for the components, rows and columns. These characters are thus reliable criteria of the yield performance on light sandy soils if other conditions, such as variety, spacing and sowing date, are kept similar. But the case is different with the number of flowers or bolls. The rows and columns that are productive in yield are different from those that stimulate flower production or bolling. This is further confirmed by the fact that boll number and boll weight are unrelated so far as components, other than effective treatments, are concerned. Thus flower counts or boll number fairly accurately forestall the yield performance of the treatments but do not serve as reliable guides in forecasting yields from field to field.

The influence of treatments on boll size is negatively correlated with the ginning percentage. Thus improvement in opening caused by a treatment leads to better development of seed.

Very little value can be attached to the significance or otherwise of the correlation coefficients corresponding to the error component, unless these are based on very high number of degrees of freedom, for the sources of variations in these cases are complex and uncontrollable and influence of causal factors cannot be further resolved into components. The same remarks apply to treatments whose effects are insignificant.

PROGRESSIVE GROWTH DATA

The progressive data is illustrated by graphs (Figs. 3, 4 and 5) and dealt with briefly. The effect of N which alone is the most potent factor, is depicted.

Study of Fig. 3 reveals that nitrogen does not increase height appreciably up till 22 August but after this the differences magnify with the advance of time. Deceleration sets in from 5 September, rather rapidly in control, and marks the onset of flowering. Height curve for the plate aplication of nitrogen remains at a uniformly

low level, due to the inclusion of some plants with shorter internodes in such plots, until the addition of nitrogen on 16 August diverts its course. Even though a change in the colour of leaves was observed within 10 days of the late application, it took about three weeks for the plants so treated to get in level with the controls. Thenceforth they gradually gained ascendency over the untreated ones. The supplementary dose begins to stimulate elongation not until five weeks after its addition. As elongation practically ceases after 3 October all over, a falling off in the effectiveness of the supplementary dressing is natural. It may be further noted that the curve for the late application remains at a lower plane throughout and runs parallel to that for the early application. This also proves that even when nitrogen is applied before sowing time it expresses itself in growth from the flowering phase onwards when untreated plots begin to show symptoms of nitrogen starvation.

The response to the single dressing is well marked on node development. The late application is able to catch up the early one. Lower response to the supplementary dressing is again evident.

Essentially the same remarks, as for height, apply to the curves for the internodal length.

Dry matter. The natural logarithms of the total dry weight ($\log_e$ W) for the nitrogen treatments are given in Table XVII to enable the detection of small differences in the early stages. It will be seen on plotting these values that the effect of nitrogen applied early appears on the plants sampled on 11 August and of the late application on 8 September. The differences tend to be cumulative.

Percentage increase in height and dry weight. The differences in height between the successive stages are expressed as percentages of the respective final heights for the treatments, *o*, n_l, n_e, and n_e+n_l [Fig. 4(*a*)]. The growth rates similarly derived from the dry-weight data are given in the same figure at the top. The dates of irrigation have been shown by arrows.

The curves for height are bimodal in form. The second maximum about 29 August synchronizes with the commencement of flowering. It is also the time when the applications of nitrogen and water begin to show their effect on growth. That is why this maximum is higher in the manured as compared with the control. After the second maximum is attained, the rate of increase all over falls progressively, though the treated plants grow comparatively more vigorously than the untreated ones. In the case of the double application, the rate falls most slowly. The first maximum is the result of the combined effect of the first two irrigations given at short intervals on 5 and 17 July. A study of Table XVIII furnishes evidence in support of this view. The characteristic increase in height during the interval between the secon and the third turn for measurement is correlated with the elongation of the internodal length only. Node number during the same interval shows no corresponding increase. The importance of water for enlargement phase of growth is evident. It must, however, be noted that once the maximum at the fifth interval is obtained, the internodes at the main axis do not

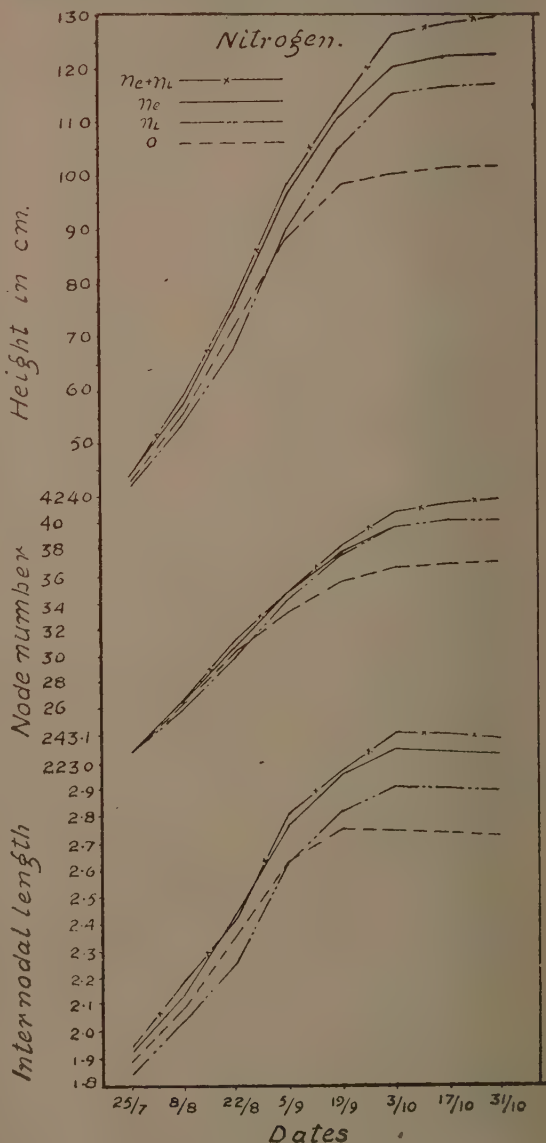

FIG. 3. Effect of nitrogen on height, node number and internodal length

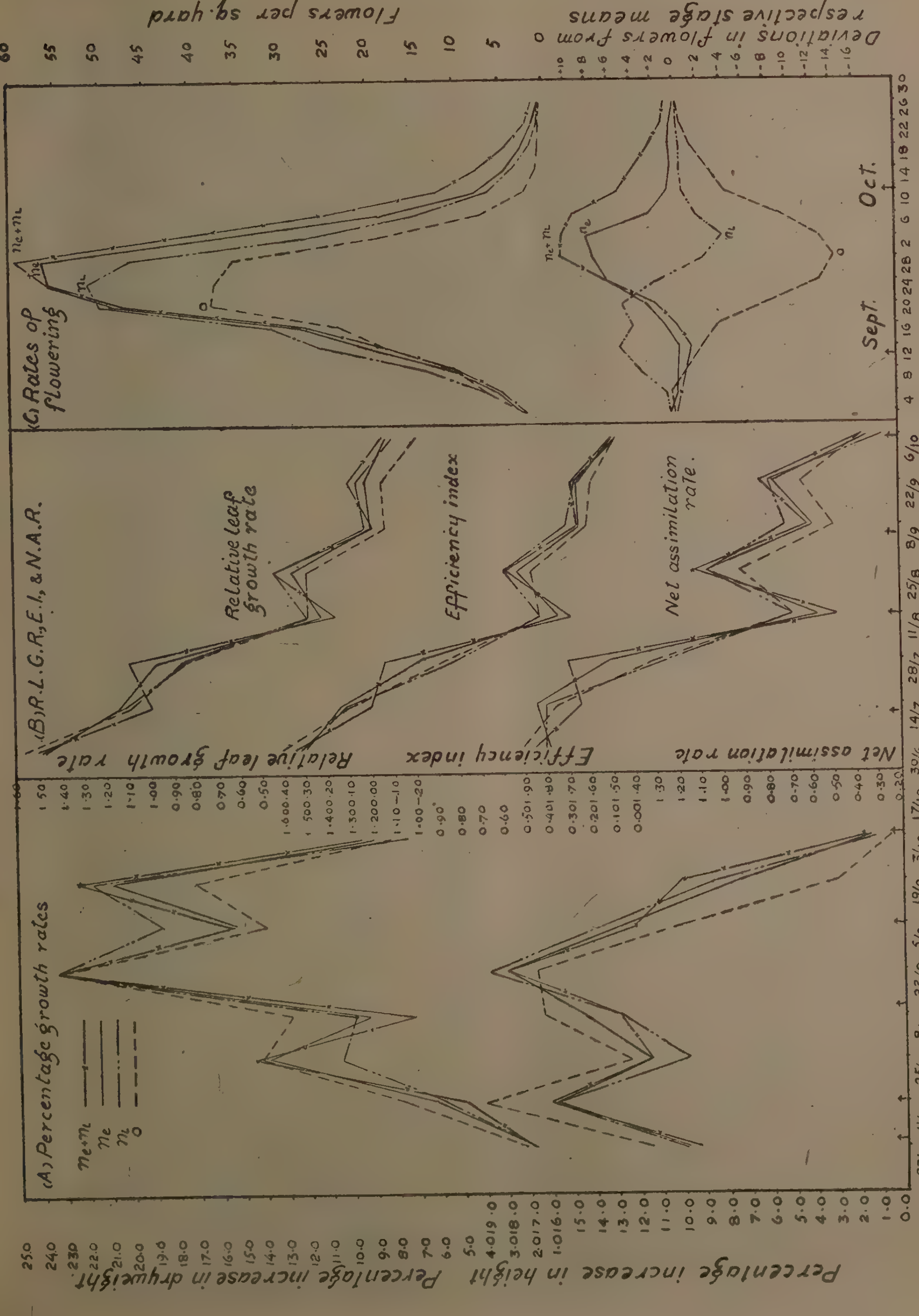

FIG. 4. Effects of nitrogen on rates of growth and flowering

FIG. 5. Effect of nitrogen on the relative distribution of dry matter in parts at different stages
(Portions shaded with vertical lines represent stems ; blank space—green leaves ; horizontal lines—shed leaves ; and squares-bolls)

TABLE XVII

The effect of nitrogen on dry weight (log_e W)

	30/6	14/7	28/7	11/8	25/8	8/9	22/9	6/10	20/10
o	1·38	3·00	4·29	5·17	5·59	6·07	6·28	6·49	6·57
n_l	1·40	2·93	4·26	5·10	5·53	*6·13*	6·44	6·71	6·79
n_e	1·50	3·01	4·36	*5·34*	5·70	6·25	6·50	6·76	6·85
n_e+n_l . . .	1·51	3·07	4·28	*5·40*	5·70	6·28	6·55	6·83	6·93

lengthen at a rapid rate due to pressure of fruiting and, therefore, elongation no longer shows periodicity with the dates of watering.

The curves for percentage increase in dry weight indicate that the maximum output of dry matter, during a unit time interval (a fortnight), that amounts to about 24 per cent of the total dry matter in all the treatments, centres round the 1 September. The diagram possesses a central tendency which synchronizes with the maximum elongation of the main axis and the onset of flowering. Another peak is exhibited by the dry weight curves irrespective of the treatments, about 29 September which marks the time of maximum flowering. This later maximum which is more pronounced in the treated as compared with the untreated plants, is to be attributed to rapid increase in dry matter when the bolls develop. Finally, the rate falls to equally low values in all the series.

TABLE XVIII

Percentage increases in node number and the internodal length

(Untreated plants)

	II-I	III-II	IV-III	V-IV	VI-V	VII-VI	VIII-VII	IX-VIII	X-IX
Node number . .	16·88	14·77	10·05	11·03	8·56	5·88	2·82	0·84	0·27
Internodal length .	10·24	*19·10*	7·33	9·51	10·13	4·45	..	..	..

There is a distinct evidence of prolonged growth activity due to nitrogen. During flowering, the plant grows more vigorously in the presence of nitrogen than in its absence.

Relative leaf growth rate, efficiency index and net assimilation rate

These rates were determined by the following formulae given by Gregory [1926].

Relative leaf growth rate	$\log_e L_2 - \log_e L_1$
Efficiency index	$\log_e W_2 - \log_e W_1$
Net assimilation rate	$\dfrac{(W_2 - W_1) \times (\log_e L_2 - \log_e L_1)}{L_2 - L_1}$

Where L_1 and L_2 are dry weights of green leaves at the consecutive stages of sampling. W_1 and W_2 denote total dry weights comprised of stems, green and shed leaves, and flower-buds and bolls, at the two stages.

These different rates calculated as above are plotted in Fig. 5 (*b*) for the nitrogen effects.

Relative leaf growth rate in the absence of manuring gives a falling curve, throughout. The rate is maximum to start with, i.e. six weeks after sowing, and drops to zero about 15 September. Early applications of nitrogen appear to have accelerated the rate of leaf growth about the first week of August. The effect of all types of nitrogen treatments, however, is clearly, visible during flowering. The rate for the treated series does not attain negative values, except in the last sample and this, again, is a proof of prolonged vegetative activity with nitrogen applications. Negative values are obtained in the control about one month earlier.

There is a close similarity between curves for leaf growth rates, efficiency index and net assimilation rate. The points of inflections correspond very closely and the influence of treatments is also similar. One point of difference must, however, be mentioned. The relative rate of increase in the total dry matter falls less rapidly since the plant goes on gaining in dry weight at the reproductive stage. Whereas negligible amounts of fresh leaves are produced after the first week of September, and even negative values for leaf growth rates have been obtained on account of rapid senescence and translocation of substances from the leaves to the developing bolls, still the attached leaves are synthesizing actively at this stage at about 1/3 the maximum rate as can be seen from the N.A.R.

The two maxima during the later stages of growth, exhibited prominently by N.A.R., correspond with the peaks in the percentage growth rate. Equally important is their coincidence with the commencement and the flush of flowering.

The rate of flower production. The 4-day totals of flowers produced per square yard are shown for the entire flowering period in Fig. 4 (*c*). The effect of nitrogen on flower production is very well pronounced and what is more important is that this effect is distributed over the entire flowering period in the case of the late application. The effect of late application begins with the commencement of flowering, reaches the maximum during the interval of maximum flower production, and persists till the complete cessation of flowering. The effect of early application starts somewhat later. The bulk of the increase is confined to the period of maximum flowering and the effect continues to the end. The peak is also reached eight days later in the case of early and early plus late applications as compared with control. Thus early applications have delayed flowering in contrast to the late.

The effects of nitrogen in flowering are further illustrated in Fig. 4 (*c*) (bottom). The deviations in the flowers produced under o, n_l, n_e, and $n_e\ n_l$. from the respective stage means of all treatments, have been plotted for each of the 15 stages. To start with, there are no differences among treatments except that the late application separates out, suggesting precocity. Other curves diverge with time, attain maximum differences after a month, and again converge to main point. Up to 24 September, higher rate of flowering is maintained in plots receiving late application. Thereafter, the plots treated before sowing gain superiority. The values for control remain below the main line, throughout. Though flowering extends over two months, more than 50 per cent of the flowers are produced during the 12-day period, from 20 September to 2 October. The effect of nitrogen also is proportionately greater during this interval.

Relative distribution of the total dry matter in parts

The effect of nitrogen on the percentage distribution of dry matter in parts at the different stages are illustrated by histograms (Fig. 5). There is no effect of early application of N at any stage so far as the ratio of stems is concerned. The relative distribution of other parts is, however, affected. The proportions of dry matter of the green leaves and the boll material are relatively higher in the last two stages under early application as compared with that of the control. The converse is true of the old leaves. n_1 plants are still more efficient in the production of flower-buds and bolls and the extra increase over the early application proceeds at the expense of stem proportion. This effect is outstanding in all the stages after the late application is given. A more rapid fall of the senescent leaves ensues in the control after 22 September, so that percentage

of green functioning leaves remaining on the plant is the least in the absence of nitrogen.

A study of the progressive changes in the relative distribution of dry matter in parts from stage to stage reveals interesting features. More than 80 per cent of the total plant weight consists of the assimilating matter when the plants are seven weeks old. As the plants advance in age the leaf weights go on falling in proportion to the non-assimilating material (stem, bolls, senescent leaves). In other words, with the advance of season increasingly larger proportions of the synthetic products of the leaf are utilized for the formation of stems and branches and less and less material is spared for leaf growth. This explains the falling leaf rates. An increasing amount is continually being incorporatd in the structural frame work which in turn does not manufacture food and resembles idle capital. Therefore, not only the leaf growth rate but also the relative rate of increase in dry matter decreases. The fall is, however, less rapid because, as explained by Heath [1937], the non-assimilating material produced by leaves is included in the total dry matter but not in the leaf.

Discussion

Nitrogen is the most potent factor that affects the growth and yield of the American cotton plants, on light sandy soils in the Punjab. Meristematic activity, extension growth, flower production, bolling, the opening of bolls and the yield, are all greatly depressed at low levels of this essential element. At the fruiting stage, deficiency of nitrogen results in the development of *tirak* symptoms. The leaves turn prematurely yellow as their nitrogen concentration falls below a critical level (2·5 per cent of the leaf dry-matter), and are ultimately shed. Growth slackens and practically ceases by the middle of September. New points are not laid rapidly and the developing sympodia are not adequately spaced. Lastly the bolls develop imperfectly and contain immature seed.

None of these symptoms appear if nitrogen is supplied in time. Even visual observations reveal prominently the differences between nitrogen-fed and control plants. The leaves in the former case remain fresh and dark green during the fruiting period in marked contrast to the untreated ones. The concentration of nitrogen in the leaves does not fall as rapidly as in the control and this forecasts the final performance of the plant. The correlated influence of nitrogen applications on the internal N-concentration in leaves and the growth, under abundant supply of water, are given in Table XIX.

Table XIX

Relation of percentage nitrogen content of leaves to growth

Treatment	Per cent N in leaves			Height (cm.)			Total dry weight (gm.)			Dry weight (gm of green leaves.)		
	25 Aug.	22 Sept.	20 Oct.	22 Aug.	19 Sept.	17 Oct.	25 Aug.	22 Sept.	20 Oct.	25 Aug.	22 Sept.	20 Oct.
o	2·55	1·76	1·36	70·2	99·5	103·1	276	540	717	160	204	154
n_e	3·16	2·71	1·99	76·5	117·2	129·3	313	718	1,029	180	271	258
n_l	2·70	2·57	1·91	68·2	109·8	122·2	253	628	912	147	239	236
$n_e + n_l$	3·11	3·11	2·49	75·1	117·9	133·8	323	738	1,108	184	272	290

Nitrogen application proportionately reduces senescence in leaves and prolongs leaf activity during fruiting. The plant grows as it reproduces, the internodes lengthen, bearing points increase, and bolls, which are better spaced and better fed, attain perfect development. Nitrogen stimulates co-ordinated growth in all aspects and is, therefore, mainly responsible for the significance of coefficients of correlations between development and yield, against treatments. As leaf growth rate and net assimilation rate are kept up at a higher level during vital part of plant's life supply of carbohydrates does not run short under nitrogenous manuring.

It must, however, be stated that nitrogen does not materially modify the inherent growth characteristics of the plant. The nature and trends of the growth rates are much less affected. The maxima in the treated and the untreated series are reached at the same time whether growth is expressed as percentage increase or as relative rates of increase in total dry matter or leaf weights alone. The main difference is that the growth rate falls off steeply after 1 September or so in the control, while it declines gradually during the reproductive phase in the treated series.

Prolonged growth does not imply delay in the commencement of flowering and deferred maturity.

Flowering sets in as quickly in the manured as in the unmanured plots. There is, in fact, an early tendency for slightly higher rate of flower production, if the application is made just before flowering. The time of maximum flowering is only slightly delayed by nitrogen. This is followed by a rapid decline in flower production. The bulk of the increase through nitrogen is confined to the zone of maximum flowering. The later period also contributes to the increase in the flowers produced by the early applications. The crop in the treated plots does not arrive late. Increasing trends in yield appear in the first picking and are established by the middle of December.

There are other qualitative differences between the two times of application also. Although the early application is better fitted to promote vegetative growth it also influences yield of *kapas* proportionately. Therefore the efficiency for production of seed cotton per unit dry weight is only slightly affected. The late application definitely raises the efficiency of the plant for the gain in boll material is proportionately greater than the gain in the vegetative organs. However, the two times of application do not significantly differ from each other in actual yield.

In practice, therefore, it is immaterial when the application is made provided nitrogen is deficient and it is not given too late. The last date beyond which use of nitrogenous manures would be unremunerative is a matter to be decided by further experiments. It can, however be tentatively put forward on the basis of growth data that nitrogen must become available to the plant by the time it passes through the phase of maximum growth activity, i.e. before 1 September.

Water also influences the development of the cotton plant but the response is much smaller in magnitude. Water mainly operates through increase in the extension phase but not the meristematic activity. The increase in yield under heavy watering is wholly contributed by increase in boll size. The inter-relation of water and nitrogen is important but its significance depends upon the nitrogen status of the soil. If the basic soil supplies are low or have been exhausted through intensive system of cropping water is not likely to be limiting and nitrogen alone will control growth and yields. Thus response to nitrogen would be spectacular and to water only small and additive. On the other hand, when the soil has been allowed to recuperate under the influence of natural agencies, water would begin to exercise its limiting effect. Under these conditions, unless the duty of water is simultaneously raised, augmented dressings of artificial fertilizers are likely to give but meagre responses. It would thus be worth while to raise water supply for increasing the effectiveness of nitrogen.

Potash alone or in combination has not affected plant development in any year. Evidence concerning the effectiveness of superphosphate is inconclusive. In one of the experiments the effect has been negligible, and in the other it was appreciable in the absence of both nitrogen and organic manure. In the presence of nitrogen, superphosphate was ineffective in both the years. Thus neither potash nor superphosphate acted as limiting factors. It follows, therefore, that potassic and phospahtic reserves are only slowly being depleted and the limit to their exhaustion has not been reached under normal agricultural conditions.

Summary

The investigation describes the results of two field experiments of the multiple-factor type with 4F Punjab-American cotton, on light sandy soils at the Lyallpur Agricultural Farm. In the first experiment, the main effects and interactions of nitrogen, phosphorus, potassium, organic manure and water supply were studied. In the second experiment, two times of application of nitrogen were included as distinct factors and organic manure was omitted. The remaining factors were the same as in Experiment I.

The cotton in the first experiment followed a one-year fallow. The later experiment was conducted under intensive system of cropping.

The investigation has brought out facts of physiological interest and practical value. The main findings have been summarized below.

(1) Nitrogen is the most potent factor that stimulates vegetative and reproductive development on light sandy soils. It brings about co-ordinated development of the plant in all directions and the effects are both quantitative and qualitative. Nodes, flowers, bolls, internodal length, dry weight, boll weight and yield are all affected favourably by its use. Nitrogen is, therefore, not only important for meristematic activity but also for extension growth and proper maturation of seed and lint.

(2) Nitrogen prolongs the functional activity of the plant and delays senescence. The net assimilation rate, leaf growth rate and efficiency index remain at higher levels during flowering in the N-treated plants as compared with the controls. Nevertheless, nitrogen does not materially modify the inherent growth characteristics, as the general trends with peaks and depressions are not shifted by its application.

(3) Nitrogen applied early or late does not delay the onset of flowering. The peak point is only slightly shifted. The major portion of the increase

in flowers due to nitrogen is recorded in the period of maximum flowering.

(4) The August application of nitrogen is definitely more efficient in the production of cotton per unit dry matter as compared with the one made before sowing. There is, however, only a small and insignificant difference in the actual yields in favour of the late application.

Single dressing of 50 lb. N per acre, made early or late, is more effective per unit of nitrogen than the combined dose of 100 lb. per acre.

(5) Heavy watering significantly increases the internodal length, boll size, and yield but the responses are small in magnitude. Increased water has practically no influence on the meristematic activity.

(6) There is a strong interaction between nitrogen and water on soils allowed to recuperate, by fallowing and cultivation prior to cropping. Under these conditions, nitrogen added depends on extra water supply for its full effect. If cotton follows an exhaustive crop such as *toria*, nitrogen gives larger responses even under normal water supply and effect of increased water duty is merely additive.

(7) Potassium, singly or in combination, has not shown any effect on any of the observations recorded.

(8) Phosphorus has shown beneficial effect in the absence of organic manure and nitrogen, only in the first experiment.

(9) Phosphorus or potassium neither interact with each other, nor do they enhance the utility of nitrogen. Thus they can neither replace nor augment nitrogen under field conditions.

(10) There are high correlations between yield and other characters, i.e. height, dry matter, flowers, bolls, and boll weight. Treatment yields are closely associated with the growth behaviour and the reproductive development. Developmental records, therefore, are fairly accurate guides to the ultimate performance of treatments in yield under similar cultural conditions.

Acknowledgements

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STUDIES IN INDIAN CEREAL SMUTS

VI. THE SMUTS ON *SAWAN* (*ECHINOCHLOA FRUMENTACEA*)

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Sawan (*sama, banti, sawank* or *kuthiraivalli*) is a less important cereal cultivated on a small scale in several parts of India. The grain is usually eaten by the poorer classes of people, either parched or boiled in milk with sugar, and in eastern India it is mixed with rice in the manufacture of rice beer. The crop also yields a valuable forage and it was exploited some years ago in the United States of America as a ' billion dollar grass '.

The plant was first named *Panicum frumentaceum* by Roxburgh in 1820 but seven years later, in 1827, Link transferred it to the genus *Echinochloa*. In Hooker [1897] it is referred to as *Panicum Crus-galli* var. *frumentacea* Trim. and Hitchcock [1935] calls it *Echinochloa Crus-galli* var. *frumentacea* (Roxb.) Wight. In 1928 Blatter and McCann named it *Echinochloa colona* var. *frumentacea* and six years later Fischer [1934] independently proposed the same name for it, without presumably knowing that Blatter and McCann [1928] had already done so. Sampson [1936] prefers the binomial *Echinochloa frumentacea* (Roxb.) Link which is accepted at Kew.

The crop is free from fungous diseases of major importance excepting for two quite distinct smuts which may cause damage. The first of these is *Ustilago Panici-frumentacei* Brefeld and the second *Ustilago paradoxa* Sydow and Butler. A third smut which attacks it is reported in this paper.

Ustilago Panici-frumentacei was collected by Major A. Barclay in October 1890 in the vicinity of Simla and sent to Brefeld for determination. Brefeld [1895], after consulting Lindau and Hennings, came to the conclusion that the smut was a new species to which he gave the above name. A portion of the type specimen was kindly sent to me by Dr E. Ulbrich, Kustos, Berlin Botanical Museum, in 1939 for examination.

Brefeld [1895] states that in a smutted ear not all the grains are attacked. The attacked ones are double the size of the healthy grains and they are filled with pulverulent spore masses, the individual spores being spherical, brownish and 7-9μ in diameter.

A second collection of this smut was made by C. A. Barber at Nambur, Guntur District in 1902 and was identified by Sydow and Butler [1906]. This specimen which is in the *Herbarium Cryptogamae Indiae Orientalis* agrees very well with the type. Two more collections have since then been made in the Madras presidency, one at Razole, Godavary district and the other at Nanganeri, Tinnevelly district and both of them are in the Herbarium of the Government Mycologist, Coimbatore. Portions of these collections that are available to me for examination consist of immature sori and do not show the spore structure clearly.

The second smut attacking this crop, *Ustilago paradoxa*, is likewise ovaricolous. It also attacks only a few grains in an ear but its spores are larger and have a perfectly smooth surface. While the spores of *U. Panici-frumentacei* germinate by the formation of a septate promycelium and lateral and terminal sporidia, those of this smut give out a long, branched and septate hypha without forming a true promycelium or sporidia. This smut has been recorded from Pusa in Bihar, from Sind and also the Bombay province.

In 1907 Butler collected yet another smut at Pusa on this same host which he identified as *U. Panici-frumentacei* and which he [1918] has described and illustrated. A comparison of this smut with the type at once indicated that an error had been made in its determination.

The smut causes considerable deformity of the host, turning it into a twisted mass of shoots with aborted ears. Sori occur not only in the inflorescence but on the nodes, on the young shoots and at the axils of the older leaves. The spores are spherical with thick blunt echinulations. While Brefeld's fungus is restricted to the ovaries, only a few of which are attacked, this smut aborts and completely destroys the entire inflorescence. If sori had formed on the stems, leaf axils, etc. there is little doubt that Brefeld would have mentioned that fact. The spore surface of Brefeld's smut is stated by him to be rough ; I find that it is minutely echinulate ; it is by no means covered ' with thick sharp spines '. The Pusa collection is undoubtedly not *U. Panici-frumentacei*.

Tracy and Earle [1895] described a smut on *Echinochloa Crus-galli* which forms large, irregular swellings on the nodes and in the inflorescence which is entirely destroyed. The sori are protected by a tough hispid membrane which is derived from the host plant and which ultimately ruptures disclosing the black spore masses. Tracy and

Earle [1895] named it *Ustilago Crus-galli* and, independently, Magnus [1896] first named it *Cintractia Seymouriana* but later [1896] corrected the name to *Cintractia Crus-galli* (Tracy and Earle) Magnus. The spores of the fungus are bluntly echinulate to verrucose. Two specimens distributed by Sydow (*Ustilagineen Nos. 125* and *179*) are available for examination. The smut found by Butler in 1907 at Pusa on *Echinochloa frumentacea* and identified as *U. Panici-frumentacei* is undoubtedly this smut. Neither Tracy and Earle [1895] nor Magnus [1896] speak of any, distortion of the host in describing it, which symptom is prominently featured in the Indian collection. But in the morphological characters of the spores, there is little doubt that the two smuts are identical and that the Indian smut is *Ustilago Crus-galli*. Since Magnus [1896] placed this smut in the genus *Cintractia* and McAlpine [1910] agreed with that view, the concepts about this genus have considerably changed. Only those smuts whose spores form an agglutinated, sometimes even an amorphous, mass that is difficult to separate, are at present placed in that genus. Cifferi even tries to restrict it to the smuts occurring on Cyperaceae with which view I am not inclined to agree. In any case, the spores of the smut under study are powdery and I think that there is no necessity to change the genus into which Tracy and Earle [1895] had originally placed it.

Formal descriptions of the three smuts follow :

1. USTILAGO PANICI-FRUMENTACEI Brefeld, Unters. Gesammt. Mykol. 1895, 12 : 103.

Syn. *Ustilago trichophora* var. *pacifica* Lavroff, Trav. Inst. sci. Biol. Univ. Tomsk, ii, 1936.

Ovaricolous, not all ovaries in an ear attacked; ovaries swollen to twice or three times their normal size ; sori covered by the seed-coat which otherwise smooth and shiny, is rendered hairy ; opening by means of a pore at apex. Spore masses pulverulent, deep black brown. Spores spherical, subspherical, a few ellipsoidal, 'Buckthorn brown' (Ridgway), 5·9-9·7μ in diameter, with a mean of 8·3μ ; epispore thick, minutely echinulate ; germinating by means of septate promycelium producing both lateral and terminal sporidia.

On *Echinochloa frumentacea*, Simla, October 1890, leg. A. Barclay (*Type*) ; Nambur, Guntur Dt. 9-10-1902, leg. C. A. Barber, *No. 461* ; Razole, Godavery Dt. 28-8-1910 ; Nanganeri, Tinnevelly Dt. 12-1-1912.

Leach [1932] reports the occurrence of this smut in Nyasaland. Lavroff [1936] has made it a synonym of *Ustilago trichophora* (Link) Kze var. *pacifica* Lavroff but neither his original paper nor his specimen is available and it is not possible to confirm his conclusion. *Ustilago trichophora* was described on *Echinochloa colonum* (L.) Link, (=*Panicum colonum* L.) and it slightly resembles *U. Panici-frumentacei* but the spores of the former are larger, viz. 7·4-11·2μ, with a mean of 9·4μ. Even if it is a variety of *U. trichophora* then its name will have to be *U. trichophora* var. *Panici-frumentacei* (Brefeld) *comb. nov.* rather than the one proposed by Lavroff [1936] much later,

2. USTILAGO PARRADOXA Sydow and Butler, in Sydow, Ann. mycol. Berl. 1911, 9 : 144.

Ovaricolous, not all the ovaries in an ear attacked ; sori not greatly exceeding the size of the normal grains, covered by a tough, slightly hairy, grey membrane, exposing a black, pulverulent spore mass on being ruptured. Spores almost spherical, oval, 'Tawny olive' (Ridgway), with granular contents, 7·8-11·2μ in diameter with a mean of 9·7μ ; epispore entirely smooth, thin ; germinating by the protrusion of a long, branched hypha without forming true promycelium or sporidia.

On *Echinochloa frumentacea*, Pusa, 2-9-1907, leg. E. J. Butler, *No. 890* (*Type*) ; Mirpurkhas (Sind), 8-10-1919, leg. G. S. Kulkarni ; Bombay province, 18-9-1920. leg. M. N. Kamat.

Kulkarni [1922] has shown that this smut is externally seed borne and that it is rather common in Sind. Leach [1932] states that it occurs in Nyasaland.

3. USTILAGO CRUS-GALLI Tracy and Earle, Bull. Torry bot. Cl. 1895, 22 : 175.

Syn. *Cintractia Seymouriana* Magnus, Ber. dtsch. bot. Ges. 1896, 14 : 217.

Cintractia Crus-galli Magnus, Ber. dtsch. bot. Ges. 1896, 14 : 392.

Ustilago Panici-frumentacei sensu Butler (*nec* Brefeld), Fungi and disease in plants, 1918, p. 239.

Sori entirely destroying the inflorescence, also on stems especially at nodes, on young shoots and in axils of older leaves ; shoot infection causing considerable deformity resulting in a twisted mass of leafy shoots, with sometimes aborted ears ; sori large, those on stem up to half an inch in diameter, swollen, covered with a hispid, grey membrane made up of host tissue on rupturing which a pulverulent, black spore mass is exposed. Spores spherical to slightly ellipsoidal, 'Mikado brown' (Ridgway), 8·9-11·9μ in diameter with a mean of 10·6μ ; epispore thick, covered with blunt, dense echinulations, even verruculose ; germinating by formation of a typical, septate promycelium with lateral and terminal sporidia.

On *Echinochloa frumentacea*, Pusa, 4-10-1907, leg. E. J. Butler, *No. 889*.

SUMMARY

1. A short account of the nomenclautre of sawan, a minor cereal grown in India, is given and its correct name has been shown to be *Echinochloa frumentacea* (Roxb.) Link.

2. The crop is attacked by two smuts, *Ustilago Panici-frumentacei* and *Ustilago paradoxa*, both of which are re-described. A third smut, incorrectly identified as *U. Panici-frumentacei* is shown to be *Ustilago Crus-galli*.

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STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT IN THE PUNJAB

IV. A NOTE ON THE STATISTICAL STUDY OF JASSID POPULATION

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Amongst the host plants of jassids in the Punjab, cotton is the most important as regards area, cash value and general economic importance. The relationship of the host and the pest in this crop has, therefore, been studied in great detail. The method of estimating the population of this pest on cotton is of fundamental importance and in a previous publication of this series [Verma and Afzal, 1940] one method of comparing the arithmetic means of the jassid population on any two varieties has already been described. These studies have now been amplified and are described here. The present method is of general applicability and has been employed by Williams [1937] in his studies on the number of insects caught in a light trap.

The population of the pest was estimated by the three methods on a large number of varieties from the American varietal test plots laid out according to Fisher's randomized block system during 1937-41. The procedure employed in these methods was as follows :

1. *Sweeping*. This method is useful only in ascertaining the adult population of the pest. The instrument employed was a hand-net 13 in. in diameter with a muslin bag 27 in. long and a wooden handle 27 in. in length. Adults were caught from each bed with 16 forward and 16 backward strokes of the net. The insects thus collected were later counted.

2. *Counting*. Average-sized plants (three to five) were selected from each bed in each repetition and all the living nymphs were counted on all the leaves by slowly turning them over.

3. *Fumigation*. Three to five normal plants were selected from each bed in each repetition and each plant was in turn enclosed in a fumigating chamber. A sheet of white paper was placed below the plant and the plant fumigated by pumping calcium cyanide from the hole at the top of the fumigating chamber. Dead nymphs and adults were counted on the plant as well as on the white paper.

The data thus collected was subjected to statistical analysis. It may be, however, said that in all insect census, there are great possibilities of arriving at wrong conclusions, as very often th calculated mean infestation is upset due to th swamping of results in a series of observations b very high numbers. The study of insect popula tion over a long range of time invariably give rise to skew distributions and covers a wide range The degree of infestation in such cases cannot b computed merely from the arithmetic means an the application of statistical formulæ als become invalid. Thus in all such studies th data requires such a transformation as would ac like the square root transformation for low num bers but like the logarithmic transformations fo large numbers. Williams [1937] in his studies o the number of insects caught in a light trap ha used the transformation — $y = \log_{10}(n+1)$. Thi function approximates to $Y=1/3\sqrt{n}$ for lo numbers, and, at values of n above 10, it depart from the square root curve and approache $Y=\log n$, from which it is practically indistin guishable at values of n above 100. Th transformation prevents the swamping of results makes the distribution normal, and affords valid basis for estimating the insect populatio on different dates or different varieties.

When it is intended to compare the degree o infestation of different strains, from the insec population counted throughout the season, by th method of the analysis of variance, the same trans formation must necessarily be employed. It i admitted that since the variance is proportiona to the square of the mean, a very highly suscep tible variety included in the experiment woul increase the error vairance and thus the smal differences between the varieties would be masked

Cochran [1938] has dealt with the difficultie in analysis of variance at some length and ha suggested transformations for different types o data, as without the use of one or the other trans formation valid conclusions cannot be drawn These transformations are given in Table I.

In order to find out the best transformation o the data available, the mean and the variance o the figures were worked out and by way of a example only one set of figures chosen at randon from the original data is given in Table II.

TABLE I

Transformations suggested by Cochran

Distribution	Data	Relation between variance and mean	Transformation	Variance in new scale
Poisson	Small whole numbers (x) . .	$V=x$	$\sqrt{x}$	1/4
Binomial	Fraction (p)	$V=\frac{p(1-p)}{n}$	$\sin^{-1}\sqrt{p}$	$\frac{821}{n}$
	Percentage (P)	$V=\frac{P(100-P)}{N}$	$\sin^{-1}\sqrt{\frac{P}{100}}$	$\frac{821}{n}$
	Numbers(x)	$V=\lambda x^2$	$\log_{10} x$	$0{\cdot}189\lambda$

TABLE II

Mean and variance for different varieties of jassid population estimated by sweeping during 1939

Variety	Mean	Range	Variance	$\lambda=\frac{\text{Variance}}{(\text{Mean})^2}$
4F . .	163·50	382	23,804·28	0·891
L.S.S. .	171·00	443	26,364·86	0·902
100F .	208·63	608	48,129·41	1·106
289F/43 .	455·75	1678	339,159·07	1·633
124F .	603·88	1592	465,244·69	1·276
289F/K.25	1314·00	3867	2,449,084·00	1·418

It will be seen that the variance for different varieties was proportional to the square of the mean and therefore the ordinary method of analysis of variance could not be applied as there was a great probability of arriving at wrong conclusions by masking the small differences amongst the varieties. It was therefore decided to use the transformation log $(n+1)$.

In order, however, to test the validity of this transformation the analysis of variance of the original as well as the transformed data were worked out and the mean infestation and the measure of significance of the actual as well as the transformed figures are given in Table III and IV, respectively.

A comparison of these two tables reveals that the transformed figures give a much more precise measure of significance than the original data. it is seen that the relative population density on the various varieties is brought out much more precisely in the transformed figures than from the original data. When a new strain is isolated at a Plant Breeding Station in a jassid infested area, the plant breeder would like to know its reaction towards this pest and if the original data is used for this purpose the danger of masking the slight differences in resistance or susceptibility become more marked. It is, therefore, necessary to transform the figures and base the conclusions on this data.

From the data presented in Table IV a comparison of the degree of infestation on different varieties as well as a comparison of the relative efficiency of three methods of estimating the population are possible.

COMPARISON OF DIFFERENT METHODS

It will be seen from Table IV that the order of the varieties remained practically the same by the different methods in all the years. The slight differences are not such as 'to cast grave doubts on the similarity of the three methods' and thus the recommendation made earlier [Verma and Afzal, 1940] holds good. The plant breeders will, therefore, be well advised to use the cheapest method of sweeping in all their future studies.

COMPARISON OF THE VARIETIES

Amongst varieties mentioned in Table IV the main interest centres round the four commercial varieties, namely, 4F, LSS, 289F/43 and 289F/K25. It is apparent that no clear distinction can be made between 4F, LSS, and 289F/43 and that these three varieties were distinctly more resistant than 289F/K.25 which was the most susceptible variety. Amongst the new strains, Jubilee cotton, being a *desi* variety, was naturally very resistant. The rest are all strains of American cotton and 199F and 148F were of practically the same order of resistance as 4F, L.S.S. and 289F/43 while 124F was comparable to 289F/K. 25. The strains 100F, 1 26F, 186F and A.C. 31 have since been rejected on account of other undesirable characters.

SUMMARY

The insect census cannot be estimated by the arithmetic means and the utility of the logarithmic transformation employed by Williams is dealt with at length. The population of the jassids on different varieties was estimated by the three methods, sweeping, counting and fumigation, for five years (1937-41). The degree of infestation on the different varieties could not be determined by the analysis of variance of the actual data as the variances in the case of the different varieties under experiment instead of being almost

TABLE III

Mean infestations in original figures

Methods	Years	Jubilee cotton	199F	148F	4F	289F/43	L.S.S.	100F	A.C. 31	186F	124F	126F	289F/K.25	S.E. ±	d_1	d_2	Remarks
	1937	..	..	..	288·40	307·70	247·60	341·90	..	..	..	..	557·10	30·421	85·527	113·275	L.S.S., 4F, 43F, 100F, K. 25
	1938	10·60	..	..	15·25	20·80	17·45	21·85	..	..	..	..	104·90	6·279	17·654	23·399	Jubilee, L.S.S., 4F, 43F, 100F, K. 25
Sweeping	1939	..	..	..	163·50	455·75	171·00	208·63	..	..	603·88	..	1314·00	195·339	560·783	752·500	4F, L.S.S., 100F, 43F, 124F., K. 25
	1940	..	..	..	89·46	135·15	156·23	..	126·77	182·38	..	283·62	261·77	26·246	74·085	98·396	4F, A.C. 31, 43F L,S.S., 186F, K. 25, 126 F
	1941	..	261·83	293·83	368·50	297·33	325·17	..	..	..	800·17	..	802·33	57·377	162·123	215·515	199F, 148F, 43F, L.S.S., 4F, 124F, K.25
	1937	..	..	..	86·55	95·35	66·05	115·15	..	..	..	..	268·05	18·531	52·282	69·421	L.S.S., 4F, 43F, 100F. K.25
	1938	1·90	..	..	4·85	5·75	4·50	7·55	..	..	..	..	69·35	4·344	12·213	16·188	Jubilee, L. S. S., 4F, 43F. 100F. K.25
Counting	1939	..	..	..	53·63	90·00	55·75	56·88	..	..	116·38	..	277·25	58·705	168·533	226·149	4F, L.S.S., 100F, 43F, 124F, K. 25
	1940	..	..	..	72·71	109·64	85·86	..	123·71	121·21	..	185·71	332·29	30·702	86·577	114·929	4F, L.S.S., 43F, 186F, A.C. 31, 126F, K. 25
	1941	..	281·92	263·75	399·08	265·42	304·33	..	..	..	949·17	..	1078·58	80·186	160·212	212·974	148F, 43F, 199F, L.S.S., 4F, 124F, K. 25
Fumig[illegible]n	1937	..	..	..	134·17	148·52	115·44	178·78	..	..	..	..	376·74	24·455	68·927	91·441	L.S.S., 4F, 43F, 100F, K. 25
	1938	3·31	..	..	9·31	9·44	9·44	12·63	..	..	..	..	103·38	5·324	15·021	19·945	Jubilee, L.S.S., 4F, 43F, 100F, K. 25

TABLE IV

Mean infestations in transformed scale

Methods	Years	Jubilee cotton	199F	148F	4F	289F/43	L.S.S.	100F	A.C.31	186F	124F	126F	289F/K.25	S.E. ±	d_1	d_2	Remarks
	1937	..	..	..	1·8197	1·8801	1·7288	1·9510	..	..	..	..	2·1763	0·0573	0·1615	0·2144	L.S.S., 4F, 43F, 100F, K. 25
	1938	0·7551	..	..	0·9586	1·0779	1·0544	1·1527	..	..	..	..	1·7703	0·0426	0·1198	0·1588	Jubilee, 4F, L.S.S., 43F, 100F, K. 25
Sweeping	1939	..	..	..	1·9889	2·2583	1·9908	2·0646	..	..	2·4309	..	2·7224	0·0379	0·1087	0·1458	4F, L.S.S., 100F, 43F, 124F, K. 25
	1940	..	..	..	1·5520	1·7229	1·6930	..	1·7024	1·6941	..	1·9825	2·0350	0·0428	0·1207	0·1603	4F, L.S.S., 186F, A.C. 31, 43F, 126F, K.25
	1941	..	2·1168	2·1260	2·1990	2·1370	2·2349	..	..	..	2·5581	..	2·5803	0·0393	0·1110	0·1476	199F, 148F, 43F, 4F, L.S.S., 124F, K.25
	1937	...	..	..	1·6257	1·6164	1·5233	1·7701	..	..	..	..	2·0912	0·0279	0·0788	0·1046	L.S.S., 43F, 4F, 100F, K. 25
	1938	0·3494	..	..	0·6020	0·6822	0·6054	0·7927	..	..	..	..	1·6417	0·0463	0·1301	0·1724	Jubilee, 4F, L.S.S., 43F 100F, K. 25
Counting	1939	..	..	..	1·4714	1·6800	1·4853	1·5456	..	..	1·7938	..	2·1169	0·0623	0·1790	0·2402	4F, L.S.S., 100F, 43F 124F, K. 25
	1940	..	..	..	1·5165	1·6103	1·5872	..	1·6401	1·6513	..	1·8877	2·0925	0·0603	0·1702	0·2259	4F, L.S.S., 43F, A.C. 31, 186F, 126F, K. 25
	1941	..	2·1129	2·1010	2·1750	2·1129	2·1456	..	..	..	2·6197	..	2·6816	0·0456	0·1287	0·1711	148F, 199F, 43F, L.S.S., 4F, 124F, K. 25
Fumigation	1937	..	..	..	1·7625	1·7740	1·6703	1·8579	..	..	..	..	2·1715	0·0190	0·0537	0·0712	L.S.S., 4F, 43F, 100F, K. 25
	1938	0·5396	..	..	0·9126	0·9685	0·9157	1·0637	..	..	..	..	1·9522	0·0397	0·1120	0·1487	Jubilee, 4F, L.S.S., 43F, 100F, K. 25

the same were of unequal magnitude and proportional to the square of the means. The data was, therefore, transformed to $\log_{10}(n+1)$.

It was found that the order of the susceptibility of all the varieties remained practically the same by the three methods and hence the breeders have been advised to use sweeping, which is cheapest and simplest of the three.

It was found that 4F, LSS and 289F/43 were equally resistant and that 289F/K25 was the most susceptible variety. Among the other American strains 199F and 148F need only be mentioned. These were practically of the same order of resistance as 4F, LSS and 289F/43. Jubilee cotton, a *desi* variety, was, however, the most resistant strain.

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STUDIES ON FRUIT AND VEGETABLE PRODUCTS

III. ASCORBIC ACID (VITAMIN-C) CONTENT OF SOME FRUITS, VEGETABLES AND THEIR PRODUCTS

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Ever since Svirbely and Szent Gyorgi [1932] showed experimentally that vitamin C was identical with hexuronic acid or ascorbic acid, its reducing property has been utilized in its estimation by the modified Tillman 2 : 6 dichlorophenol indophenol indicator method as developed by Birch, Harris and Ray [1933]. On account of its importance in nutrition, the estimation of vitamin C in fruits, vegetables and their numerous products, has in recent years been the subject of a great deal of investigation. There is absolutely no record of the vitamin-C content of the different kinds of fruit and vegetables grown in Baluchistan. In an investigation of this nature, factors like soil, climate, variety, method of handling, etc. have a profound influence on the vitamin-C content of the material. This attempt to record the findings on the subject is, therefore, fully justified. Further, the experimental data obtained have an intrinsic value in themselves.

In a study of the ascorbic acid content of some English fruit and vegetables, Olliver [1938] found that in the case of black currants, gooseberries and strawberries, the maximum vitamin-C content is obtained by early picking. On any one day of picking, however, the concentration is higher in the riper than in the less ripe fruit. In the case of gooseberries, etc., variety may greatly affect the vitamin-C content. In America, Wheeler, Tressler and King [1939] have carried out an exhaustive series of investigations on the vitamin-C content of numerous vegetables and recorded their approximate vitamin-C content in milligrams per gram of the material.

In recent years, various workers in India are engaged in studies on the vitamin-C content of fruits and vegetables. Damodaran and Srinivasan [1935] studied the vitamin-C content of some Indian plant materials like drumstick (*Moringa oliefera* Lamsk), Cashewapple (*Anacardium occidentale* Linn), *ber* (*Zizipus jujuba* Jus.), etc. Their experimental findings not only showed the existence of strikingly rich sources of vitamin-C among materials not examined till then, but also threw interesting light on the variations in the conditions in which the vitamin exists in plants. Ahmed [1935] chemically determined the vitamin-C content of a number of Indian fruits and vegetables. Mitra, *et al.* [1940] estimated the ascorbic acid content of some 96 fruits and vegetables grown in Bihar. In the mango, the ascorbic acid content of the skin was found to be twice as much as that of the pulp [Rama Sarma and Banerjee, 1940]. Workers in the Nutrition Research Laboratories at Coonoor are also engaged in studies on this subject.

All the world over, the attention of research workers is, however, now turned to a study of the changes in the vitamins during the different stages of processing of the numerous fruit and vegetable products. The literature on this subject is vast and requires careful sifting to secure concrete data. There are, however, a few reviews on the subject. 'Vitamins in Canned Foods' is the title of an exhaustive and critical paper on the subject by Kohman [1937]. In a review of the effect of processing on vitamins in fruits and vegetables, Fellers [1936] pointed out that ordinary storage and to a lesser extent cold storage for long periods in air, cause serious loss of vitamin C. Sun-drying is more destructive to vitamin C than artificial dehydration. Fermentation of fruits and vegetables is injurious to vitamin C. During canning, the more acid fruits retain more of vitamin-C than the non-acid vegetables.

Olliver [1936], who studied the effect of cooking and canning on the ascorbic acid content of fruits and vegetables, came to the conclusion that limits of variations rather than fixed values should be given to the vitamin-C content of fruits and vegetables. The percentage of ascorbic acid destroyed in both cooking and canning is comparatively small. Some plant tissues showed apparent gain of ascorbic acid on heating, a result of considerable interest in view of the recent work by Reedman and McHenry [1938] on combined ascorbic acid in plant tissues.

Mac Linn and Fellers [1938] noticed that tomato varieties and strains showed a considerable range in ascorbic acid content (74 to 249 international units per ounce ; 1 international unit of vitamin $C = 0 \cdot 05$ mg. pure ascorbic acid). The outside flesh and skin of the fruit were found to contain most of the ascorbic acid, but its highest concentration was in the seeds and in the gelatinous material of the locule section. About 25 per cent of the

original ascorbic acid present in tomato juice was destroyed when the juice was concentrated to prevent separation of suspended solids. Tomato juice stored for 400 days both in the dark and in the light did not lose more than 25 per cent ascorbic acid.

According to Charley [1939], syrup from the Baldwin variety of black currant contains as much as 101·3 mg. ascorbic acid per 100 c.c. Sills [1940] noticed that sulphur dioxide exerted the greatest preservative action on ascorbic acid content in English fruit juices and syrups. Joslyn [1941] noticed that in the case of citrus juices, sulphur dioxide was not only an excellent antioxidant, but also a preservative of vitamin-C and colour, contrary to other findings. Lal Singh and Girdhari Lal [1940] have determined the ascorbic acid content of tomato juice.

The present paper deals mainly with the effect of various manufacturing processes on the ascorbic acid content of some important fruit and vegetable products.

Material and methods

Different kinds of fruits and vegetables employed in this investigation were mostly obtained from the Government Fruit Experiment Station, Quetta, while for comparative purposes market samples also were analysed in certain cases. The material was, therefore, of known origin and the results obtained were of great use in interpreting the effect of variety, soil factor, climate, method of handling, etc. on the ascrobic acid content of the material.

The ascorbic acid content of the fresh as well as the processed fruit or vegetable was estimated by the modified Tillman 2 : 6 dichlorophenol indophenol indicator method as developed by Birch, Harris and Ray [1933]. In the case of the fresh material, trichloracetic acid was employed for getting the extract, while in the case of juices and syrups, the press extract itself was taken for the estimation of the ascorbic acid. The details are, however, given briefly in the following paragraphs.

The indicator solution

Harris and Ray [1933] recommend 0·1 gm. of the indicator in 50 c.c. water, i.e. a 0·2 per cent solution. In the present case, however, 0·145 gm. of the indicator was dissolved in water and made up to 50 c.c. to give a 0·01 M solution. The indicator solution was standardized against ascorbic acid solution which was itself standardized against iodine solution. At the end point of titration, the blue colour of the indicator changed sharply into red or slightly brownish red tint and remained so for 2-3 minutes.

Extraction of ascorbic acid

The ascorbic acid in the case of most fruits and vegetables is bound up with the tissues in varying degrees and its complete extraction is not an easy process. The cell tissues are to be broken before the solvent can extract it. The method adopted for the extraction was briefly as follows :—About 10 gm. of the fresh material was cut into fine pieces with a stainless steel knife and crushed in a glass mortar using 5 gm. of chemically pure sand, to break up the cells, and 6·25 c.c. of 20 per cent trichloracetic acid solution. The extract was filtered rapidly through muslin cloth. In some cases, the extraction was repeated twice or thrice. The combined extracts were made up to 25 c.c. so that the final concentration of trichloracetic acid in the final extract was 5 per cent.

Trichloracetic acid helps to precipitate protein matter and break up the cell walls releasing the ascorbic acid. Further, it may also stabilize the vitamin by having an inhibitory effect on the oxidizing system in the broken tissue. It is, however, not definitely known if trichloracetic acid extracts the vitamin completely from the fruit or vegetable tissue. A few experiments in this direction were carried out by varying the time of grinding, number of extractions, concentration of trichloracetic acid, and also by applying heat, etc. Olliver [1938] recommends metaphosphoric acid in addition to trichloracetic acid as it helps to prevent oxidation. In the case of fruit juices and syrups, they were titrated directly with the indicator solution. In most cases, the average of three readings was taken to calculate the ascrobic acid content. The results thus obtained for the ascorbic acid represent, therefore, what occurs in practice in the preparation of these products.

The ascorbic acid content of some important fruits and vegetables and their products are given in Tables I and II. It will be noticed that white clingstone peaches contain nearly twice as much ascorbic acid as yellow freestone peaches. Limes are rich in vitamin C and the juice contains nearly 44 mg. of it in 100 c.c. Tomatoes are quite rich in their ascorbic acid content. Green and unripe tomatoes contain only 18-20 mg. of the acid, while the ripe ones contain as much as 30 mg. per 100 gm. The juice content of tomatoes obtained by hot pressing is 73·06 per cent and the ascorbic acid content of the juice is 29·12 mg. per 100 c.c. indicating thereby that most of the acid is concentrated in the juice that can be separated by mere hot pressing. When the 'hot' pressed juice was allowed to stand overnight in an open vessel, there was a loss of 1·41 mg. of ascorbic acid only. When fresh cold-expressed juice was filtered and the filtrate taken for the estimation of ascorbic acid,

TABLE I

Ascorbic acid content of some important fruits

Experiment No.	Particulars	Ascorbic acid content (mg.)	Remarks
1	White clingstone peach, fully ripe (*Prunus persica*)	11·96/100 gm.	From Fruit Experiment Station
2	Parvin-Yellow free stone peach, fully ripe	6·02/100 „	Ditto.
3	*Kagzi* lime—good quality fruit (*Citrus medica acida*)	43·87/100 „	Market sample
4	Water melon juice (5·8 Deg. Brix. and 0·04 per cent acidity, as Citric acid) (*Citrullus vulgaris*)	5·27/100 c.c.	
5	Water melon seed, air dried	3·37/100 gm.	Not a rich source of vitamin C
6	Tomatoes (local) large red, fully ripe (*Lycopersicum esculentum*)	30·26/100 c.c.	Juice was pressed in the cold
7	Do. Yellow ripe only (acidity of juice 0·52 per cent as citric acid)	17·67/100 c.c.	Unripe tomatoes; hence the low value
8	Do. Green and unripe	19·83/100 c.c.	
9	Do. Ripe, red (Trichloracetic acid extract)	23·03/100 gm.	
10	Do. Fully ripe, juice extracted by the 'hot process' as for preparing tomato juice	29·12/100 c.c.	The juice content of tomatoes (by pressing) is 73·06 per cent. The juice appears to contain almost the whole of the ascorbic acid
11	Do. The juice from Expt. 10 allowed to stand overnight	27·71/100 c.c.	
12	Do. Juice freshly expressed in the cold and filtrate taken for estimation	32·91/100 c.c.	The clear serum contains the whole of the ascorbic acid in tomato juice
13	Peach squash (55 Deg. Brix. and 1·0 per cent added acidity, as citric acid; preserved by SO_2)	11·0/100 c.c.	Prepared from white peaches

TABLE II

Ascorbic acid content of some vegetables

Experiment No.	Particulars	Ascorbic acid content (mg.)	Remarks
1	Lettuce, fresh and green (*Lactuca sativa*)	17·01/100 gm.	From Fruit Experiment Station Garden
2	Spinach, fresh and green (*Spinacea oleracea*)	63·54/100 gm.	Do. Rich in vitamin C
3	Potato, fresh young, not peeled (Local variety) (*Solanum tuberosum*)	24·57/100 gm.	
4	Green chilli, fresh and green (*Capsicum acuminata*)	74·87/100 gm.	From Fruit Experiment Station Garden. This is a remarkable observation
5	Brinjal, fresh, small, tender purple coloured (*Solanum melongena*)	3·76/100 gm.	Ditto.
6	*Karela* (*Momordica charantia*, Cucurbitaces)—		
	(*a*) Small, tender, green 2½ in. × ¾ in. diam Juice pressed in the cold through cloth	175·5/100 c.c.	
	(*b*) Same after two days storage at room temperature (trichloracetic acid extract)	188·0/100 gm.	
	(*c*) Same as in (*a*) cut into slices and sun dried (20 per cent yield)	29·81/100 gm. of fresh vegetable, 149·05/100 gm. of dried vegetable	There is thus a loss of 83·0 per cent of ascorbic acid as a result of sun drying
	(*d*) Old, yellowish green and brittle, 7 in. × 1¾ in. in size	95·72/100 gm.	Young and tender Karela contains nearly twice as much ascorbic acid as the ripe and brittle one

it was noticed that it contained slightly more of the acid than the unfiltered juice. This slight increase in the value might be due to the fact that during filtration of a certain volume of the juice the insoluble particles are removed, thereby decreasing the volume of the filtrate, and consequently, a slightly less volume of the filtrate will be required to titrate a given volume of the indicator. The experiment also indicates that the clear serum contains almost the whole of the ascorbic acid in tomato juice, the insoluble pulp containing a negligible quantity of it. Cold-pressed tomato juice was also slightly richer in ascorbic acid than the hot-pressed juice, showing thereby a slight loss of the acid during the short period of heating prior to pressing.

In the case of vegetables, spinach, green chilli and *karela* (*Momordica charantia* Cucurbitacea) are very rich in ascorbic acid. It is a remarkable observation that green chillies grown locally contain as much as 74·87 mg. and *karela* 188·0 mg. of the acid per 100 gm. of the tissue. Lettuce and potatoes contain 17·01 and 24·57 mg. respectively per 100 gm. of the fresh tissue. The juice of *karela*, when pressed in the cold, is very rich in ascorbic acid and contains 175·5 mg. of it per 100 c.c. When the vegetable is over-ripe and yellow, its ascorbic acid content is low, being only about 50 per cent of that of the fresh tender vegetable. When the fresh tender vegetable was cut into pieces and dried in the sun without any further preliminary treatment, the yield of the dried product was 20 per cent of the fresh vegetable and it contained 149·05 mg. of ascorbic acid per 100 gm. of the powder, or 29·81 mg. per 100 gm. of the of fresh vegetable. There was, therefore, a loss of nearly 83·0 per cent of the acid during ordinary sun-drying. In spite of this, even the sun-dried powder contains nearly 30 mg. of ascorbic acid per 100 gm. which compares favourably with tomato juice which is well known for its vitamin-C content. *Karela* might prove an easily available and rich source of vitamin-C in the production of foodstuffs containing the added vitamin. Further experiments are needed to find out if by modifying the process of drying, the loss of ascorbic acid content of the vegetable can be minimized. The bitter nature of the vegetable might prove a handicap in its widespread use in the preparation of vitamin-fortified foodstuffs, but it should be possible to get over this difficulty also. This is, however, a subject that requires further investigation.

Ascorbic acid content of tomato juice

In view of its importance as a source of vitamin-C, tomato juice and related products have been the subject of a series of investigations by American workers [Mac Linn and Fellers, 1938]. During the 1939 and 1940 seasons, a number of batches of tomato juice were prepared and bottled using high quality tomatoes grown at the Fruit Experiment Station, Quetta. The method of preparation was as follows :

Fully ripe tomatoes were washed with cold water sprays, cut into four pieces and heated quickly in an aluminium vessel and kept at the boiling temperature for 5 minutes to soften the pulp. The hot pulp was then rubbed by means of glass rubbers through loose mesh muslin cloth spread over 16 mesh monel metal sieves. The juice thus screened was weighed and salt added to the extent of 0·9 per cent by weight. The juice was brought to a boil, and filled hot into sterile glass bottles of 24 oz. capacity which were then closed with crown corks and sterilized for 35 minutes in boiling water. At the end of the process, the bottles were cooled slowly by running out the hot water from the tank. The degree Brix, acidity and ascorbic acid content of the juice were determined in all cases. The data are given in Table III. It will be noticed that the Brix value of the juice varies from 6·0 to 8·3 degrees, while the percentage acidity varies from 0·48 to 0·74. The ascorbic acid content has, however, a greater range of variation. Early in August, the ascorbic acid content of the juice was only 29 mg. per 100 c.c., while about a week later when the tomato season was at its highest, it rose to 53 mg., indicating thereby that fully ripe tomatoes at their peak period are considerably richer in ascorbic acid than the early ones even when they are fully ripe. When ripe tomatoes are picked and kept in ordinary storage for two to three days only, there is only a very slight loss of ascorbic acid. Longer storage, however, may considerably increase this loss as reported by Fellers [1936]. During the 1939 season, the samples of tomatoes were collected towards the end of July when the ascorbic acid content of the juice was 26-28 mg. per 100 c.c. There was a tendency for this value to rise with advancing season. The slight increase in the ascorbic acid content of tomato juice cocktail was mostly due to the added acid through the addition of lemon juice, chilli powder and spices to plain tomato juice to convert it into the cocktail.

A well known brand of tomato juice packed in plain cans was found to contain only 12·5 mg. of ascorbic acid per 100 c.c. In our experiments, the freshly bottled juice was far higher in its ascorbic acid content. There was, however, a certain amount of loss during ordinary storage in white glass bottles for long periods.

The results of a series of experiments on the changes in ascorbic acid content of tomato juice during preparation as well as storage in white glass

bottles under sterile conditions are given in Table IV.

It will be noticed that there is comparatively little loss of ascorbic acid content during the first 20 min. when the juice is kept in stoppered glass flasks. After that period, there is a slight fall in the value and at the end of 43 hrs., the loss is nearly 35 per cent of the original value. The ascorbic acid content of tomato juice decreases with increasing period of storage of fully ripe tomatoes. It is, therefore, desirable not to keep fully ripe tomatoes long in storage before preparing the juice. There is a considerable loss of ascorbic acid in bottled tomato juice during ordinary storage. In one instance, the original ascorbic acid content of the juice was 28·65 mg. per 100 c.c., but when bottled and stored at ordinary temperature for about 11 months, the value was only 16·54 mg. per 100 c.c. indicating a loss of nearly 42·6 per cent of the vitamin.

TABLE III

Ascorbic acid content of tomato juice

Experiment No.	Date	Particulars	Juice: Yield	Deg. Brix.	Acidity per cent	Ascorbic acid	Remarks
					Per cent as citric	mg. 100 c.c.	
1	10-8-39	Large ripe, red, select tomatoes local variety	75·0	7·0	0·57	29·12	Juice screened through monel metal sieve
		Ditto . .	..	..	..	28·7	After adding salt and heating to 200°F. before filling into bottles
		Ditto . .	..	..	..	28·7	After standing overnight in an open bottle
2	11-8-39	Large, red, select tomatoes, slightly under-ripe	57·1	6·2	0·62	28·5	
3	15-8-39	Tomatoes fully ripe . .	61·9	6·5	0·48	52·65	
4	19-8-39	Tomatoes ripe . . .	71·5	6·7	0·73	40·51	Splitting of the tomato had begun
5	21-8-39	Same as in Expt. (4) stored in trays at room temperature	52·8	6·8	0·57	40·51	There was not any change in the ascorbic acid content as a result of further ripening after picking]
6	23-8-39	Tomatoes picked on 22 August 39	70·0	6·2	0·75	35·10	
7	30-8-39	Ripe tomatoes . . .	67·4	6·3	0·63	40·51	
8	1-9-39	Tomatoes picked on 31 August ; ripe	70·4	6·3	0·74	47·86	
9	9-9-39	Tomatoes picked on 8 September ; ripe	66·6	6·0	0·70	43·87	
10	13-9-39	Tomato juice, commercial brand	..	..	..	19·5	A well-known brand of tomato juice in cans was analysed for comparative study
11	15-7-40	Ripe tomatoes of good quality	66·7	6·1	0·56	26·34	
12	20-7-40	Ditto . .	75·2	8·3	0·65	27·71	Salt was added before taking the Brix. reading
13	28-7-40	Ditto . .	65·9	6·5	0·65	30·97	Spices were added to prepare tomato juice cocktail
14	29-7-40	Ditto . .	70·7	6·5	0·63	37·61	Ditto.

TABLE IV

Changes in the ascorbic acid content of tomato juice

Experiment No.	Particulars	1 c.c. indicator = c.c. juice	Ascorbic acid content mg./100 c.c.	Remarks
1	Tomato (local variety) large red, fully ripe; juice pressed cold and filtered rapidly through muslin cloth— (1 c.c. indicator = 1·053 mg. of ascorbic acid)		..	
	Time after extraction			
	3 minutes	3·48	30·26	The juice was kept in a stoppered glass flask at room temperature
	10 „	3·30	31·91	
	20 „	3·32	31·72	
	25 „	3·40	30·96	
	60 „	3·46	30·43	
	43 hours	5·10	20·65	There is a loss of about 35 per cent of the original value
2	Tomato from Expt. No. (1) ripened further for two days in the open		28·77	The ascorbic acid content decreases slightly as a result of further ripening after picking
3	Do. after four days ripening		25·07	
4	Tomato juice bottled on 11 August 1939 and kept in ordinary storage till 17 July 1940. Original ascorbic acid content of juice 28·65 mg./100 c.c.		16·54	There was thus a loss of 42·6 per cent of ascorbic acid content during a period of storage for about 11 months

SUMMARY

An investigation has been carried out into the ascorbic acid (vitamin-C) content of a number of important fruits and vegetables and some of their products. The ascorbic acid estimations were carried out by titration against standard 2 : 6 dichlorophenol indophenol indicator.

White clingstone peaches contain nearly twice as much ascorbic acid as yellow freestone peaches.

Green and unripe tomatoes contain only 18-20 mg., while the ripe ones contain as much 30 mg. of ascorbic acid per 100 gm. of the tissue.

Almost the whole of the ascorbic acid present in tomatoes is in the juice that can be separated by cold pressing. The clear serum contains the maximum amount of the acid, while the filterable insoluble pulp contains almost nil. There is only a slight loss of ascorbic acid during the hot process of extraction.

The ascorbic acid content of tomato juice increases with the advance of the tomato season and is the maximum somewhere near the peak period of the season. When ripe tomatoes are picked and kept in ordinary storage for two to three days only, there is only a very slight loss of ascorbic acid. Longer storage may, however, considerably increase this loss.

There is very little loss of ascorbic acid in hot-pressed tomato juice during the first 20 min. of storage, after which there is a gradual fall and at the end of about 43 hrs., the loss is nearly 35 per cent. There is, however, considerable loss of ascorbic acid in bottled tomato juice during ordinary storage, the loss being as much as 42·6 per cent during storage for a period of 11 months.

Among vegetables brinjal contains 3·76 mg., lettuce 17·01 mg., spinach 63·54 mg. and potato 24·57 mg. of ascorbic acid per 100 gm. of the fresh, tender vegetable. Green chillies are remarkably rich in ascorbic acid, in one instance, the value being as high as 74·87 mg. per 100 gm. of the tissue. *Karela* (*Momordica charantia* Cucurbitacea) is the richest source of ascorbic acid among the vegetables examined. The fresh tender vegetable contains 188·0 mg. of ascorbic acid per 100 gm. of the tissue, while the cold-pressed juice contains 175·5 mg. of the acid per 100 c.c. Old and brittle *karela*, however, contains only about 50 per cent as much ascorbic acid as the young and tender

vegetable. During sun-drying, there is a loss of nearly 83·0 per cent of ascorbic acid in the case of young and tender *karela*, the dried vegetable containing 149·05 mg. of the acid per 100 gm. which corresponds to only 29·8 mg. of the acid per 100 gm. of the original fresh material.

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VARIATION IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

VI. VARIATION IN THE UNCOLLAPSED DIAMETER OF THE COTTON FIBRE

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Of the various measures that are employed to estimate the fineness of the cotton fibre, the diameter of the uncollapsed fibre appears to be the closest approximation as it gives the diameter of the undisturbed fibre cell. Equivalent to it is the diameter of the fibre swollen in 18 per cent caustic soda solution, as has been shown by Calvert and Summers [1925] and others. But the presence of immature fibres, which do not swell into rounded cylindrical shape in the caustic soda solution, would create some errors. Neglecting these immature fibres from measurement would overcome the defect, as Iyenger and Ahmad [1942] found that the mean diameter is practically the same for the mature, half-mature and immature fibres in a sample of cotton. Generally speaking, therefore, the diameter of the swollen fibre could be used as a measure of fineness. In field laboratories where fresh bolls could be procured, the uncollapsed diameter can be used as is being done in Egypt [Brown *et al.* 1932].

In this method, however, the difficulty of proper sampling is a drawback, because the wet fibres cannot be mixed thoroughly as is done in the case of dry lint. A tuft from a certain region on the seed is to be taken for the test. This raises the question of the variation of the fibre diameter on the surface of the seed. Work of Koshal and Ahmad [1932] has shown that the length and fibre weight vary considerably in the different regions of the seed. Similar variability in the fibre maturity and standard fibre weight was found by Iyengar [1941]. As the standard fibre weight is a measure of the diameter, it is to be expected that the latter also varies in the different regions of the seed. To study the extent of this variation is the object of the present work. For this purpose the uncollapsed diameter of the fibre was determined at the three regions (1) micropylar end, (2) right side (raphe facing the observer and micropyle pointing upwards), and (3) the chalazal end. These three regions would be sufficient for our purpose as the previous work has shown that the variation of the fibre characters is greatest between the micropylar and chalazal ends, the right side having nearly the same value as for the other regions.

A fairly mature boll plucked from the plant was immediately cut open and the locks were placed under water. The middle seed of one lock was taken out, the fibres were gently teased out by means of needles and a tuft of about 80 to 260 fibres sprouting exactly on the region required was separated and pulled out, the whole operation being done under water. The fibres in the tuft were arranged parallel on a Gulati and Ahmad [1935] slide, mounted in a mixture of equal proportions of glycerene, alcohol and water and examined. No fixative was used as only one or two bolls were examined each day.

The results obtained in the case of 13 bio-types of *G. hirsutum* grown under irrigation and four of *G. arboreum* and two of *G. herbaceum* grown under rain-fed conditions are recorded in Table I. One tuft taken from each of the three regions on one seed was examined for each boll.

It will be seen in the irrigated varieties of *hirsutum* that (1) in every case the micropylar end indicates a significantly higher value than either of the other two regions and (2) in eight cases, namely 3, 4, 7, 13, 14, 15, 17, and 18, the right side has a significantly higher value than the chalazal end. When the mean values for the different regions in all the irrigated cottons are considered, the micropylar end is found to be significantly greater* than the right side or the chalazal end.

The coefficient of variation is found to vary from 10·8 to 21·7 per cent with an average 15·8 per cent. The right side appears to have a lower coefficient of variation than the other two regions. The variability, which is of the same order as that found by Koshal and Ahmad [1939] for the swollen diameter, indicates that an examination of about 200 fibres would give a standard error of about 1·1 per cent.

Amongst the rain-grown cottons, the differences between the micropylar region and the other regions are not so high as indicated by the irrigated hirsutums. While in the latter case the difference was significant in all cases, in the case of the rain-grown cottons only four samples (Nos. 19, 21, 22 and 25) out of 10 record significantly higher values for the micropylar end over the right side. Between the micropylar end and the chalazal end, however, all the differences except the last three are significant. In all cases except two (Nos. 21 and 26) the right side has significantly higher value

* Significance was estimated according to student's method

TABLE I

Uncollapsed diameter in the different regions of the seed in μ

No.	Strain	Micropylar end				Right side				Chalazal end			
		No. of fibres	Value	S.E.	C.V. per cent	No. of fibres	Value	S.E.	C.V. per cent	No. of fibres	Value	S.E.	C.V. per cent
	Irrigated cottons												
	G. hirsutum												
1	X3915 Q. 7	242	24·9	0·211	13·1	217	21·4	0·212	14·6	233	21·9	0·223	15·2
2	,, Q. 10	144	24·7	0·271	13·3	164	21·8	0·239	14·0	179	21·4	0·230	14·3
3	,, Q. 11 (1)	264	23·4	0·204	14·1	164	21·4	0·212	12·7	250	20·1	0·220	17·3
4	,, Q. 11 (2)	188	24·3	0·191	10·8	263	21·5	0·163	11·7	230	20·7	0·226	16·7
5	,, Q. 12	121	24·5	0·337	15·1	247	21·0	0·195	14·6	206	20·5	0·253	18·0
6	X4383 B. 15 (1)	178	24·5	0·278	15·1	178	20·6	0·249	16·1	169	20·3	0·248	15·8
7	,, B. 15 (2)	229	24·3	0·228	14·2	233	22·4	0·183	12·4	209	21·4	0·202	13·6
8	,, B. 33	172	24·7	0·336	17·8	274	21·5	0·204	15·7	210	20·8	0·211	14·7
9	,, B. 53	118	27·6	0·640	21·7	143	22·3	0·244	13·3	169	22·9	0·256	14·5
10	,, G.	128	23·2	0·423	20·7	183	20·7	0·229	14·9	204	20·3	0·236	17·3
11	X4463 A. 1	194	24·3	0·269	15·3	226	20·9	0·222	16·0	170	20·2	0·318	20·7
12	,, A. 2 (1)	135	23·6	0·318	15·9	296	20·2	0·211	18·0	210	20·2	0·201	14·4
13	,, A. 2 (2)	157	25·4	0·322	15·9	128	22·6	0·271	13·6	223	21·1	0·234	16·6
14	,, A. 3	175	24·1	0·310	17·1	189	22·2	0·276	17·0	140	20·7	0·363	20·7
15	,, A. 4	166	23·8	0·231	12·5	152	22·2	0·231	12·9	168	20·4	0·282	18·0
16	Co. 2 (1)	175	27·1	0·468	22·8	239	22·6	0·197	13·4	136	23·2	0·359	18·6
17	,, (2)	145	25·6	0·360	17·0	125	21·6	0·377	19·5	169	20·3	0·311	19·7
18	,, (3)	168	24·2	0·320	17·2	209	22·2	0·250	16·2	127	20·2	0·358	19·9
	Mean		24·7		16·1		21·6		14·8		20·9		17·1
	Rain-grown cottons												
	G. herbaceum												
19	2919	87	28·2	0·717	23·8	183	24·5	0·299	16·5	119	22·6	0·415	20·0
20	4714	84	23·6	0·452	18·5	161	24·3	0·400	20·9	166	21·8	0·372	22·0
	G. arboreum												
21	C. 6—4 (1)	83	25·0	0·719	26·6	161	20·6	0·226	13·8	184	21·4	0·269	17·0
22	,, (2)	162	23·1	0·357	19·6	184	22·0	0·303	18·6	151	20·6	0·325	19·4
23	,, (3)	93	22·5	0·484	20·8	170	21·6	0·280	17·0	153	20·0	0·300	18·5
24	C. 22—1	79	23·8	0·600	22·3	101	23·1	0·396	17·2	184	21·2	0·314	20·1
25	L. 3 4/4 (1)	153	23·5	0·385	20·2	197	21·4	0·221	14·5	173	18·4	0·339	24·2
26	,, (2)	102	21·7	0·448	20·8	216	21·2	0·256	17·7	207	20·7	0·287	20·0
27	,, (3)	149	21·4	0·336	19·1	155	22·1	0·276	15·6	203	20·7	0·220	15·2
28	6142	150	20·6	0·325	19·4	121	24·3	0·500	22·6	94	21·4	0·437	19·7
	Mean (*arboreum*)		22·7		21·1		22·0		17·1		20·6		19·3

than the chalazal region. The right side is also seen to exhibit smaller variability than the other two regions as was found with the *hirsutum* cottons.

The extent of variability appears to be greater among the rain-fed cottons than among the irrigated ones.

It will be seen from the foregoing that (1) in most cases, the diameter is greater at the micropylar end, less at the right side and still less at the chalazal end, (2) the coefficient of variation is smaller at the right side than at the other two regions, (3) the variability appears to be greater in the rain-grown *arboreum* cottons than in the irrigated *hirsutum* ones. It, therefore, follows that for comparative purposes the fibres from one region should be examined in all cases. It is suggested that this region should be the right side of the seed on account of the middle value it gives, the smaller

coefficient of variation it possesses and the smaller percentage of immature fibres present in this region as compared with the chalazal end. About 200 fibres from this region would give a fairly accurate value of the uncollapsed diameter. The value obtained by this method, however, may not necessarily be the same as that obtained from a tuft of fibres representative of the whole sample of lint.

Acknowledgement

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DESIGN OF A SIMPLE QUARTZ MICRO-BALANCE

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(With one text-figure)

Research workers on textiles are often confronted with the problem of weighing a small mass of fibres as rapidly and accurately as possible. Several types of balances have been designed to give a high degree of accuracy and the object of this note is to describe a quartz balance of the Nernst [1902] type which can be constructed easily and inexpensively, which does not require a telescope and which is capable of giving fairly high accuracy in weighing a small mass. Although the balance has primarily been designed for cotton research, it can be readily used in any type of micro-analytical work.

Description

The balance which is shown in Fig. 1 consists of (1) a tripod stand, (2) a U-shaped brass frame carrying the quartz fibre and a glass capillary beam, and (3) the arm supporting a graduated quadrant.

The tripod stand is mounted on three levelling screws $B_1B_2B_3$, and supports a vertical pillar A_1A_2 having a hole of about 3 cm. depth drilled at its upper end. The cross bar of the U-shaped brass frame $C_1C_2C_3$, which measures about 16 cm. in length passes through the cylindrical rod D, which is slipped into the hole in the pillar and is fixed with the screw E. The upright C_1 can be moved parallel to itself with the help of the screw F. The central pillar A_1A_2 also supports the arm G_1G_2 carrying a graduated quadrant H_1H_2 which is pasted on a mirror J. The quadrant can either be rotated round K_1K_2 or moved horizontally along it or it can be moved up or down by sliding the rod K_1K_2 in the socket G_2. Screws are provided to fix it in any desired position. A plumb line M is provided to level the instrument.

The quartz fibre N has a diameter of about 45-50 microns and is stretched between the two uprights C_1 and C_3. The capillary tube $P_1P_2P_3P_4$ which serves both as the arm and the pointer, having a diameter of 0·5-0·6 mm. is attached to the quartz fibre with the help of a small aluminium piece O which is a special feature of the instrument, and is shown separately in Fig. 1(a). It is made from an aluminium rod measuring about 1·5 cm. in length and having a diameter of about 0·1 cm. and weighing about 50 mg. The middle part of the rod is flattened out by filing, while one end is threaded to take a very small nut R which may be made from brass or preferably aluminium. A narrow slot is cut into the flat portion near the upper end. The capillary tube is provided with a fine needle to serve as a pointer at one end P_4 while at the other end P_1 it is bent into a V to carry the pan Q. It is then bent at right angles twice near the middle, so that the two arms P_1P_2 and P_3P_4 are parallel, their lengths being approximately 15 cm. and 20 cm. respectively, while the vertical part P_2P_3 is only about 0·6 cm. long. The capillary tube is placed in the slot near the upper bend P_2 so that the short vertical part P_2P_3 rests against the flat part of the aluminium piece O and is fixed with a little sealing wax.

Construction and calibration

The quartz fibre N is cemented at both ends to the top surfaces of the uprights C_1 and C_3 with sealing wax. It is advisable to use a heated metallic blade with a wooden handle to melt the wax on the uprights, instead of appyling the mild flame directly. In order to fix the capillary tube to the aluminium piece, O the latter is placed across a narrow slit, cut in a metallic or wooden sheet, which is itself held in a horizontal plane by a stand. Holding the capillary tube in position as explained above a drop of molten sealing wax is put on it so as to cement the two rigidly. In order to fix the aluminium piece O (carrying the capillary tube) to the quartz fibre it is best to remove the U piece, $C_1C_2DC_3$, with the quartz fibre attached to it out of the tripod stand and hold it in a retort stand in such a position that the centre of the quartz fibre rests on the flat part of the aluminium piece O just below the capillary bend P_3 and the fibre is fixed to the piece with sealing wax. Afterwards the frame with its attachments is gently removed and placed on the tripod stand A_1A_2 (Fig. 1). The quartz fibre is gently stretched by means of the screw F so that it is taut. A lightpaper pan Q weighing about 10 mg. is suspended from the V bend of the arm P_1P_2, while the other arm P_3P_4 is counterpoised by means of a small quantity of molten wax. The position of the quadrant is adjusted so that the pointer P_4 moves radially over it.

For all these cementing operations it is best to use a hot bar or a microflame.

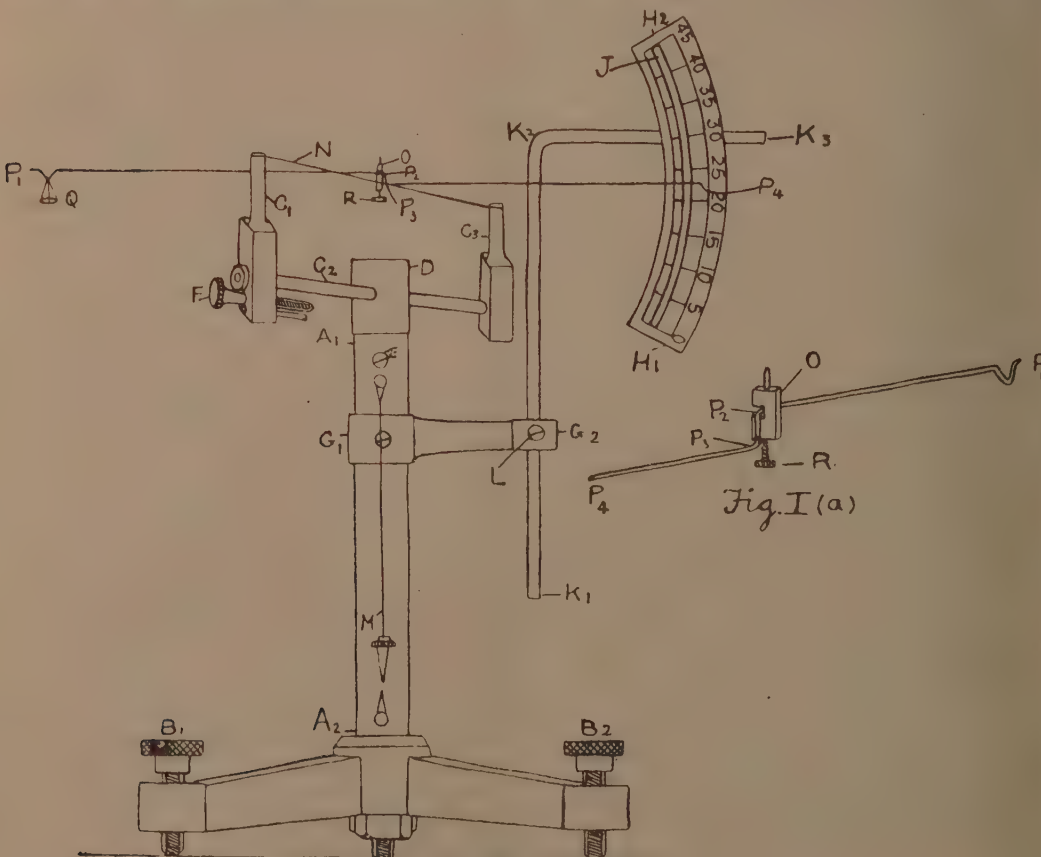
The balance will be found suitable for weighing up to half a milligram with a sensitivity of about 0·0025 mg. If it is required to weigh up to 4 mg. the small nut R weighing about 140 mg., should be gently screwed to the piece O when the sensitivity will be of the order of 0·02 mg. The sensitiveness of a balance of this type can be altered, to some extent, by altering the length of the capillary arm, but in doing so, care must be exercised to see that the fibre does not give way under the combined action of its weight and the tension. It can also be altered to some extent by changing the length of the quartz fibre, but if the fibre is made very long in order to increase the sensitiveness, the balance becomes unsteady owing to constant small vibrations. The sensitiveness can be altered to a very considerable extent by using quartz fibres of different diameters, as the torsional rigidity varies directly as the fourth power of the radius. If it is intended to increase the sensitiveness by using a finer fibre, the dimensions of the capillary tube, the aluminium piece O, etc. will have to be modified suitably so that the fibre can support their weight without snapping.

The balance should be placed on a solid base and enclosed in a suitable case to prevent vibrations due to draught.

Calibration of the balance for the two ranges 0–0·5 mg., and 0–4 mg. is done by using known standard weights. If weights of the intermediate values are not available small pieces of a non-rusting metallic wire of uniform diameter may be used for this purpose. The observed differences may be plotted against the corresponding weights and the graph which should be checked from time to time may be used to read the weight of a small bunch of fibres, etc.

Conclusions

This balance was designed in the first instance for use with the Ahmad-Nanjundayya Stapling Apparatus [Ahmad & Nanjundayya, 1936]. As such the small nut R should be gently screwed on the aluminium piece O as the range of the



Figs. 1. and 1(*a*)

balance is 0–4 mg. It can also be used for the determination of fibre weight per inch of cotton, and for this purpose the small nut R should be removed so as to increase the sensitiveness to 0–0·5 mg. range. These are, however, only two of the many uses to which a balance of this type may be put. By making small changes in the shape or design of the boat Q used as a receptacle for the object to be weighed, it may be used in any micro-analytical work in which extremely small quantities have to be weighed fairly quickly and accurately. The fact that quartz fibre possesses a high tensile strength and freedom from elastic fatigue, is not affected much by changes in temperature and humidity, and can be drawn out with a uniform diameter confers special advantages on a balance of this type. The time required for the pointer to come to rest in each weighment is found to be of the order of 20–25 sec. It may be possible to reduce this time by using a damping device but as the time is not very large it was thought desirable to aim at simplicity of design and construction. The balance has been tried for some time at the Technological Laboratory of the Indian Central Cotton Committee and has been found to give consistent results in good agreement with those yielded by other sensitive balances. This will be seen from Tables I and II given in the Appendix. Table I shows the results of weighing small tufts of cotton on a torsion balance having a range of 0-5·0 mg. and the balance described in this paper. Table II shows the results obtained for unit fibre-weight of five different cottons with the Quartz Micro-balance ordinarily used in this Laboratory having a range of 0-0·5 mg. [Denham, 1924] and the new balance described in this paper. It will be seen that in both cases the agreement is remarkably good.

It may be useful to indicate roughly the cost of construction of this balance. The cost of construction would depend upon several variable factors, namely, ruling prices of materials, overhead charges, etc. It is estimated that under the present-day conditions the cost of construction would be in the neighbourhood of Rs. 100 only. This should be regarded as a very rough estimate.

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APPENDIX

TABLE I

Results obtained with a Torsion Balance and the New Quartz Micro-Balance (0-4·0 mg.)

Tuft No.	Weight in mg.	
	Torsion Balance	New Quartz Micro-Balance
1	0·97	0·94
2	1·01	1·00
3	1·05	1·05
4	1·26	1·25
5	1·25	1·25
6	1·77	1·82
7	1·93	1·94
8	1·96	1·95
9	2·04	2·01
10	2·49	2·46
11	2·60	2·62
12	2·95	3·01
13	3·05	3·06
14	3·43	3·51
15	3·77	3·71

TABLE II

Results obtained with the New Quartz Micro-Balance and the one, ordinarly used in the Laboratory, (Denham type, 0-0·5 mg.)

Cotton	Unit fibre-weight 10^{-6} gm.	
	Quartz Micro-Balance (Denham type)	New Quartz Micro-Balance
1	2·95	2·86
2	4·05	4·08
3	2·98	2·98
4	3·97	3·88
5	4·73	4·68

A STUDY OF SOIL HETEROGENEITY IN RELATION TO SIZE AND SHAPE OF PLOTS IN WHEAT FIELD AT RAYA (MUTTRA DISTRICT)

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(With three text-figures)

In field experiments, soil heterogeneity is the major factor which contributes towards a very large portion of variation. The work on the uniformity trials done in India and abroad shows that the plot size and shape exercise a considerable influence on the efficiency of the experiment and that usually there is an optimum plot size for a particular crop on a particular soil. In the United Provinces, although field experiments with randomized block and latin square patterns have been conducted since the year 1933-34, no investigation has so far been made to determine optimum size and shape of plots for different crops, the size of plots employed being determined partly on the consideration of convenience of agricultural operations and partly on the knowledge of the results of the uniformity trials conducted elsewhere. The need for finding out a suitable plot size for various crops in the United Provinces has, therefore, long been felt. This paper deals with the results of the uniformity trials on wheat, conducted at Government Research Farm, Raya (Muttra District), during the *rabi* season of 1939-40.

Literature

A catalogue of uniformity trials has been recorded by Cochran [1937] and reviewed by Fairfield Smith [1938]. In India studies on the experimental errors in relation to size and shape of plots have been conducted on sugarcane by Sayer *et al.* [1936], Bose *et al.* [1939] and Vagholkar *et al.* [1940]; on cotton by Hutchinson and Panse [1935] and Panse [1941]; on rice by Bose *et al.* [1936]; and on wheat by Krishna Iyer [1942].

Procedure

The general method of studying the problem consists of dividing the field in small plots and calculating standard errors for plots of different size and shape by combinations. To eliminate the effect of soil heterogeneity, some workers have superimposed randomized block layout, while others have used latin square layout. The efficiency of the layout for a particular area depends upon the type of soil heterogeneity existing in the field and the method by which it is eliminated. In the present paper soil heterogeneity has been eliminated by three methods, (*i*) between the rows, (*ii*) between the columns, and (*iii*) between adjacent lots, and attempts have been made to study the intrinsic relation between the residual variation and the size and shape of plots. The first two methods of eliminating soil heterogeneity are similar to those of a latin square. The third method was first suggested by Papadakis [1937] and has been employed by Bartlett [1938] in recovering information from replicated field experiments with large blocks. The method consists of calculating fertility index for each plot as the mean of the four plots all round it. Taking the actual yield as y and the mean of the four plots as x, analysis of co-variance is worked out as usual. In the case of edge and corner plots, the means of three and two contiguous plots respectively were taken as the values of x. These three methods have been applied to the data from the uniformity trial of wheat C 13 with a view to study soil heterogeneity in relation to size and shape of plots for field experiments on wheat at Raya.

Material

The trial was laid out in 1939-40 *rabi* at the Research Farm, Raya, which represents the soil and climatic conditions obtaining in the western U. P. Wheat C 13 variety was sown over an area of 180 ft. × 243 ft. with 324 rows on a field of average fertility. It had wheat during 1938-39 *rabi* and was fallow during 1939-40 *kharif*. The seed was sown behind *desi* plough in rows 9 in. apart, the length of each row being 180 ft. The crop was irrigated twice during the season and other usual operations were carried out according to the practice at the farm. At the time of harvest 18 rows on both sides and 10 ft. at the end of the field were discarded to eliminate border effects and an area of 160 ft. × 216 ft. with 288 rows was harvested in small units, each being 2 ft. 3 in. broad with three rows 20 ft. long. Thus there were 96 units across the rows and eight units along the rows. The total number of unit plots thus obtained was 768. The yield of grain for each unit plot was weighed and recorded separately and is given in the appendix.

Statistical analysis

The 768 units of plots were grouped to give plots of 3 rows, 6 rows, 9 rows, 12 rows, 18 rows, 24 rows, and 36 rows wide and 20 ft., 40 ft. and

80 ft. long. The side along the wheat rows was treated as length and that across the rows as breadth irrespective of magnitude. The data was analysed by Fisher's analysis of variance. Systematic soil variation along the rows and columns was eliminated and standard errors for plots of different size and shape were calculated from the residual mean square. The results are given in Table I (*a*).

TABLE I

Standard error per plot in per cent of the mean for plots of different size and shape

Length	Breadth						
	2 ft. 3 in. (3 rows)	4 ft. 6 in. (6 rows)	6 ft. 9 in. (9 rows)	9 ft. (12 rows)	13 ft. 6 in. (18 rows)	18 ft. (24 rows)	27 ft (36 rows)
(a) Before eliminating variation due to correlation between adjacent plots							
20 ft.	21·8	17·8	15·2	14·0	11·9	10·2	8·6
40 ft.	19·5	16·0	13·6	12·4	11·1	8·9	7·8
80 ft.	18·7	15·6	13·6	12·0	11·0	8·7	7·2
(b) After eliminating variation due to correlation between adjacent plots							
20 ft.	12·4	11·1	9·9	9·0	7·9	6·7	5·8
40 ft.	11·6	10·5	8·7	7·8	6·7	5·7	5·2
80 ft.	11·4	9·4	7·6	6·8	5·4	4·4	2·6

The standard error is highest for the smallest plot (2 ft. 3 in. × 20 ft.) and decreases gradually when both the length and breadth of the plot are increased. Table I (*b*) shows the standard errors for plots of different size and shape after further eliminating variations due to correlation of adjacent plots by Papadakis' method. There is an appreciable reduction in the standard errors due to adjustment by the fertility indices for all plot sizes. Comparing the standard errors for plots of different size, it is seen that errors decrease with increased plot size. Fig. 1 shows the relation between the average standard error and the plot size.

When the plot size is increased from 45 to 270 sq. ft. there is a steep fall in the standard error but by further increase beyond 360 sq. ft., the fall becomes gradual. This shows that the plot size for field experiments with wheat should be between 270 and 360 sq. ft. Iyer [1942] while studying the data of uniformity trial on wheat at Karnal has found 400 sq. ft. as the optimum size of plot for field experiments with wheat. Comparing standard errors for plots of different shape [Table I (*a*) and (*b*)] it is observed that long, narrow plots are not less variable than broad plots of the same size. This finding differs from those of other workers.

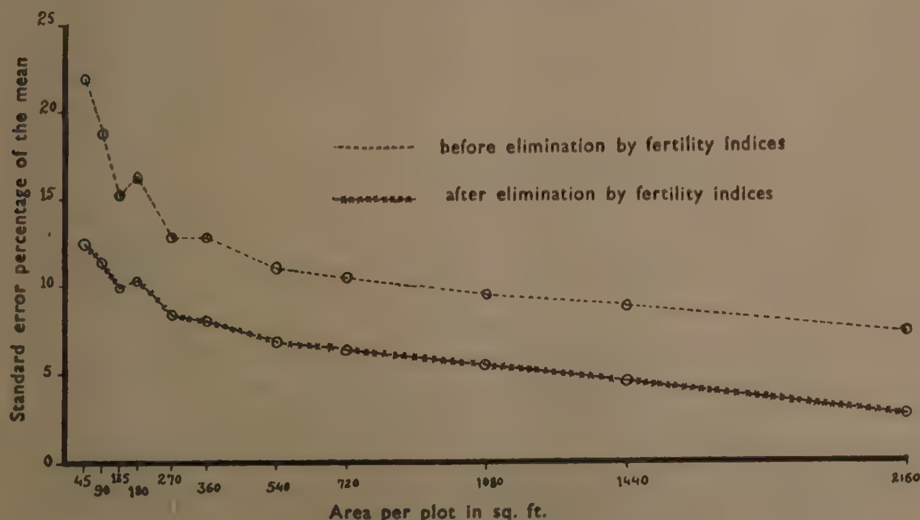

FIG. 1 Variability in relation to size of plots

Table II shows the percentage efficiencies (100 × variance before adjustment/variance after adjustment) of adjustment by the fertility indices for plots of different size. It is interesting to note that efficiency is above 200 for all plot sizes. This shows that Papadaki's method is useful in further reducing error variance and thus increasing the precision of the experiment. According to Papadakis [1937] the reduction in the error is most marked when the plots are long and narrow. This is corroborated by the data presented in Table II.

TABLE II

Percentage efficiencies of adjustment by the fertility indices for plots of different size and shape

Length	Breadth						
	2 ft. 3 in.	4 ft. 6 in.	6 ft. 9 in.	9 ft.	13 ft. 6 in.	18 ft.	27 ft.
20 ft. . .	310	262	238	241	224	234	218
40 ft. . .	281	232	246	254	272	242	223
80 ft. . .	270	275	319	308	418	390	754

Fig. 2 shows the relation between average efficiency and plot size. When the plot size is increased from 45 to 135 sq. ft., the efficiency falls rapidly. From 135 to 270 sq. ft. it is practically the same, but by further increasing the plot size beyond 270 sq. ft., the efficiency rapidly rises. This implies that while Papadakis' method is efficient for designs with plot size of 45 sq. ft., it is still more efficient for plots of 1080 sq. ft. and above.

DISCUSSION AND CONCLUSION

A study of standard errors from the residual variance, after variation due to all known components are eliminated, for plots of different size and shape is useful in determining the optimum size and shape of plots for field experiments. In the present case three components of soil heterogeneity have been eliminated, (*i*) rows, (*ii*) columns, and (*iii*) correlation between adjacent plots.

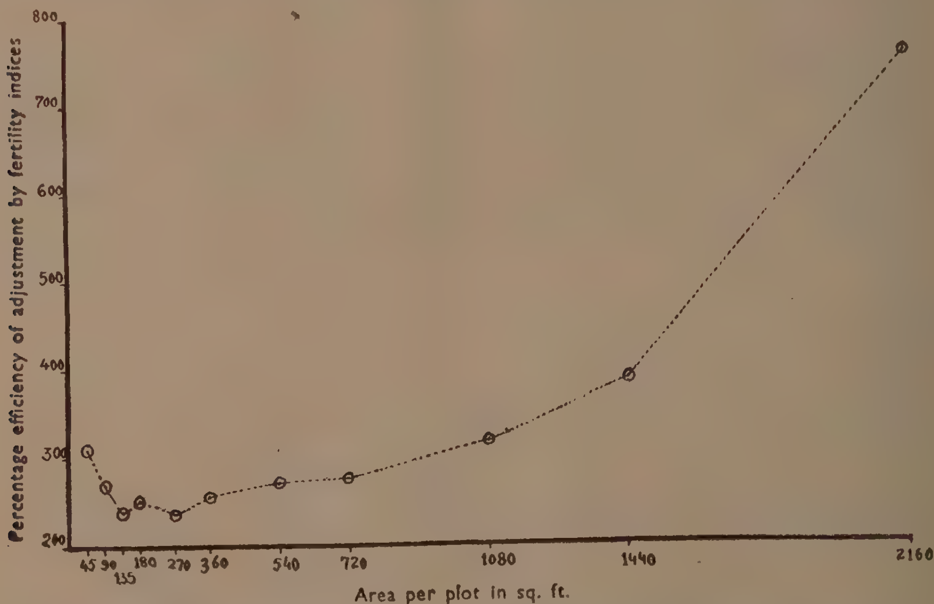

FIG. 2 Average percentage efficiencies of adjustment by fertility indices for plots of different size

While rows represented on an average only 2 per cent variation, columns represented 80 per cent of the total variation. Adjustment by the fertility indices has further eliminated variation of 10 per cent. Thus a very large portion of soil heterogeneity was observed between columns. The contour fertility map (Fig. 3) shows that there are stripes of high and low fertility along the wheat rows. History of the field reveals no explanation for this phenomenon, as an average field usually found on the farm was selected for the trial.

From the study of standard errors it is observed that the relative variability is diminished as the plot size is increased. This shows the intrinsic relation between variability and plot size after all known sources of variation are removed; but since the area is limited the increase in plot size results in the reduction in the number of replications which increases the variability. In order to find out the relative efficiency of a plot size corrected for the number of replications it is necessary to take both the plot size and number of replications into consideration. This is done by calculating the relative efficiency of the plot size as shown by Sayer *et al.* [1936] and is obtained by multiplying the variance per plot by the number of ultimate units, contributing to the total of that plot and taking the reciprocal.

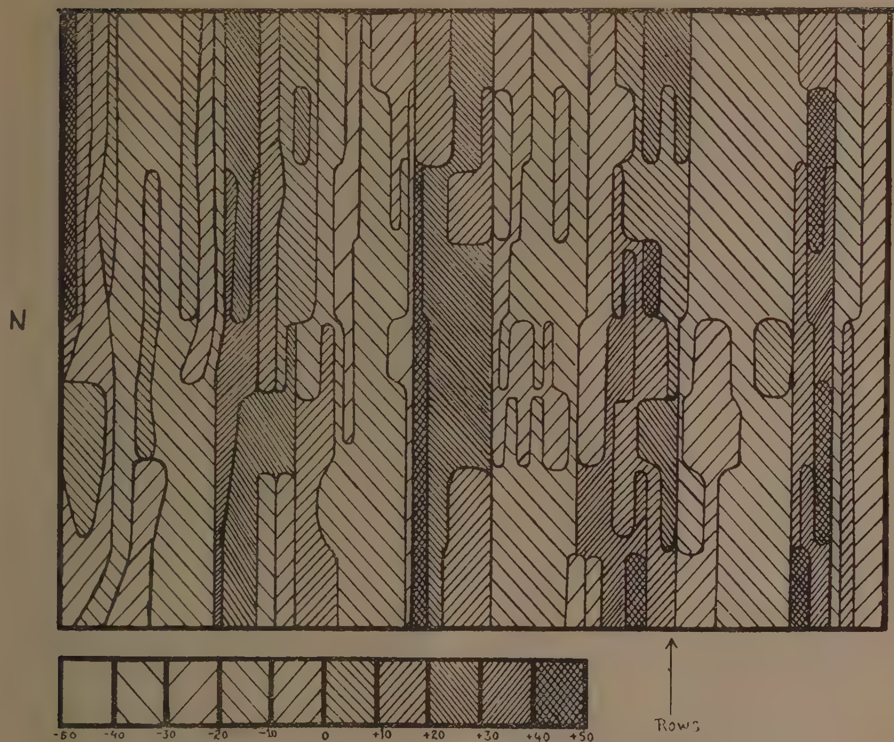

FIG. 3 Fertility contour map from data of wheat uniformity trial at Raya

Taking the efficiency of the smallest plot as 100, the efficiencies of other plots are calculated. This is shown in Table III.

TABLE III

Relative efficiencies for plots of different size and shape

Length	Breadth						
	2 ft. 3 in.	4 ft. 6 in.	6 ft. 9 in.	9 ft.	13 ft. 6 in.	18 ft.	27 ft.
Before eliminating variation due to correlation between adjacent plots							
20 ft.	100	75	69	61	57	57	54
40 ft.	63	47	43	39	33	38	33
80 ft.	34	24	22	21	17	20	19
After eliminating variation due to correlation between adjacent plots							
20 ft.	100	63	53	48	41	43	38
40 ft.	57	35	34	32	29	29	24
80 ft.	30	22	22	21	22	25	47

It is seen that the smallest plot (20 ft. × 2 ft. 3 in.) is the most efficient and efficiency rapidly decreases as the plot size is increased. Here too, long plots are not more efficient than the broad plots of the same size. The rapid fall of efficiency with increased plot size suggests that the plot size should be as small as could be managed conveniently. In other words, efficiency could be better attained by increasing the number of replications. From a study of the relative variability and efficiency, a plot size of 270 sq. ft. seems to be optimum for varietal trials at the farm. For agronomic trials it may be increased to 360 sq. ft. if necessary for convenience of agricultural operations. In progeny row trials for breeding of new strains, due to limited quantity of seed, the plot size has necessarily to be small and efficiency could be attained after allowing sufficient number of replications.

The relation between efficiency of adjustment by fertility indices and the plot size is interesting. While a high correlation between adjacent plots was observed for plot of the smallest size, a still higher correlation was noticed for plots of the biggest size. This shows that Papadakis' method is more efficient for designs with small plot size or

with very big plot size. This finding is of great use in further reducing the experimental error and thereby increasing the precision of the field experiments. At this place, however, it is necessary to point out the theoretical limitations of Papadakis' method arising by the double use of each plot yield for x and y in the analysis of covariance. Bartlett [1938] investigated the applicability of this method from theoretical point of view and concluded that where the number of plots per block is large, the method should be approximately valid. The results obtained by Papadakis' method in the present investigation are, however, subject to this limitation.

Summary

The data of uniformity trial with wheat C 13 conducted during 1939-40 *rabi* at the Cotton Research Farm, Raya, was studied with a view to determine optimum size and shape of plots for field experiments with wheat. The utility of Papadakis' method of adjustment by the fertility indices was also investigated in relation to plots of different size. The following conclusions are drawn :

(1) Considering the standard errors and relative efficiencies, a plot size of 270 sq. ft. has been found to be optimum for wheat varietal trials. This may be increased up to 360 sq. ft. for agronomical trials, if necessary. For progeny row trials, efficiency of the small plots could be maintained after allowing sufficient replications.

(2) Long plots have no advantage over broad plots of the same size.

(3) Papadakis' method was found to be useful in further increasing the efficiency, particularly for plots of very small size and of very big size. The limitations to the applicability of this method have been pointed out.

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APPEN

Uniformity trial with wheat CI3 at the Government Research

(Yield of grain per

60	60	58	39	37	45	27	34	25	41	47	28	40	30	57	49	39	30	29	70	52	68	61	38
78	68	48	40	31	46	27	26	29	32	37	28	33	30	52	43	40	32	32	72	70	48	66	39
94	54	37	48	40	48	26	28	33	28	53	32	34	24	58	50	38	35	34	78	76	70	79	44
77	55	43	40	41	49	33	30	36	27	40	33	34	34	60	49	41	37	33	82	73	66	78	40
55	33	34	43	35	35	26	24	35	45	30	38	34	31	41	37	43	31	70	84	82	84	94	34
46	33	49	45	46	34	27	33	30	46	28	36	26	34	46	32	34	30	88	101	78	69	81	40
68	38	51	43	37	41	25	26	36	40	32	41	29	33	48	38	35	38	82	86	69	64	78	38
37	18	41	31	31	53	41	39	43	44	33	30	34	39	32	25	23	13	82	70	72	44	73	25
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

33	48	52	48	48	37	36	30	31	20	32	35	40	34	43	45	33	50	64	42	50	67	72	38
40	42	48	67	46	32	43	26	30	20	26	34	34	35	36	38	16	64	50	40	41	50	76	40
41	46	35	45	43	29	30	28	24	24	28	28	33	36	43	26	16	90	75	64	70	61	50	48
43	54	60	52	45	30	31	24	31	29	38	32	46	35	34	28	19	84	63	73	57	72	51	66
38	51	67	29	52	20	40	25	23	40	32	38	30	22	37	23	17	90	89	64	67	71	68	47
60	66	64	40	52	29	36	28	21	32	31	31	31	35	40	33	23	77	87	76	60	73	54	72
36	46	59	39	44	39	28	28	32	36	40	35	30	28	25	26	21	80	66	77	70	61	52	58
32	44	52	42	57	40	38	42	26	49	32	37	21	25	32	25	12	76	86	72	60	59	52	40
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

X

arm at Raya (District Muttra) during 1939-40 Rabi

—unit ½ oz.)

2	40	39	38	44	24	28	40	33	32	28	30	41	34	39	53	49	45	43	76	55	50	56	74	26	31	38	38	33	32	34	34	26	22	22	31	35	45	55	32	57	31	40	28	42	37	45
8	32	30	40	34	30	25	27	33	35	23	28	36	38	38	44	36	42	48	73	64	51	65	60	24	30	44	38	33	36	35	40	26	28	31	27	36	43	44	71	90	24	46	33	44	34	38
4	21	32	39	28	23	40	32	33	48	20	25	43	36	35	61	43	46	50	57	51	52	49	46	24	28	24	33	33	33	30	36	24	30	35	32	33	69	53	86	82	30	43	32	34	36	49
7	35	39	51	33	24	40	29	24	40	23	31	43	43	38	62	72	59	65	78	94	41	42	56	26	25	29	24	46	44	37	32	24	33	28	32	40	63	60	73	81	30	36	32	40	40	44
2	42	28	41	38	37	32	40	34	32	18	41	35	46	78	75	66	55	56	63	57	48	42	30	30	36	37	38	36	30	33	24	54	50	48	46	48	58	73	54	76	31	46	40	38	43	47
7	26	35	33	38	29	31	40	37	37	20	40	43	42	76	60	61	53	65	66	68	66	56	27	35	39	28	36	36	40	46	34	42	34	30	33	34	55	66	58	91	34	56	41	44	38	42
2	28	33	44	29	25	29	32	25	29	26	46	76	58	76	54	54	60	74	46	48	73	64	30	29	23	33	40	31	24	28	26	47	26	31	32	33	64	82	50	84	35	55	29	36	24	39
6	29	28	30	39	26	25	30	29	29	12	26	44	37	81	74	75	87	90	58	48	62	60	38	41	40	36	39	32	38	31	24	32	40	32	37	36	86	111	78	72	36	65	38	44	37	46
0	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96

SELECTED ARTICLE

SOME RESULTS OF STUDIES ON THE DESERT LOCUST (*SCHISTOCERCA GREGARIA* FORSK.) IN INDIA*

By Y. Ramchandra Rao, M.A., F.R.E.S., F.I.Ac.Sc., Late Locust Research Entomologist, Imperial Council of Agricultural Research, India

[A voluminous general report on the organization and the results of the locust investigations carried out in India in 1931-1938, under the auspices of the Imperial Council of Agricultural Research, was officially submitted to the Council by Rao Bahadur Y. Ramchandra Rao in 1941, but its publication has been postponed until after the war.

A copy of the report has been sent, by permission of the Council, to the Anti-Locust Research Centre at the Imperial Institute of Entomology, for information, and it proved to contain a wealth of data and of ideas, only some of which have been published in various preliminary papers by its author and by his colleagues. In view of the great scientific and practical value of the report, it appeared necessary to make at least its main findings available to other entomologists working on the subject, and permission has been obtained from the author and from the Imperial Council of Agricultural Research for the publication of some sections of the report. Only a few sections, selected and edited by Dr B. P. Uvarov, are being published below, and it should be stressed that their publication in the abridged form does not in any way detract from the value of the complete report, which, it is hoped, will be published at the earliest opportunity for the benefit of all workers on the locust problem.]

Studies on the development

Maximum number of successive generations possible in a year

Husain and Ahmad [1936] have proved that there is no diapause in the Desert Locust, *Schistocerca gregaria* Forsk., in any stage of its development and that as many as eight successive generations may be obtained within a year at a constant temperature of 40°C., about seven generations at 36°C., and five at 30°C. Under natural conditions, however, there is always a considerable fluctuation of temperatures, diurnal as well as seasonal, so that the duration of a brood would naturally vary in accordance with the prevailing temperatures. In nature, the main factor in the breeding of the locust would appear to be the presence of an optimum amount of moisture in the soil. This, under natural conditions, is dependent on requisite rainfall, and as apparently the mass-multiplication of the locust depends on optimum conditions of rainfall, it was considered desirable to measure the potentialities of increase possessed by the insect by rearing it under confinement in cages in the actual desert environment, but providing it with the optimum amount of soil-moisture. Pairs of locusts kept in cages and provided with fresh food and with wet sand at the bottom were found breeding satisfactorily and producing a succession of generations, although in nature in the neighbouring breeding grounds, only a single generation was observable.

The results of breeding permit the following deductions to be made :

1. During late spring and in summer, when the average monthly mean temperatures vary from 28 to 30°C., the periods of sex maturation, egg incubation and hopper development are shortest, but in spring and autumn, when the means range from about 22 to 26°C., they tend to be much longer, and in winter development is extremely slow. In summer, sex maturation may occur in 3 to 4 weeks, eggs may hatch in about 14 days and hopper development may be completed in about 31 days.

2. In mid-summer, the life-cycle, from oviposition by the parent generation to egg-laying by the progeny, may be completed in about two months and a half, but since it is much longer in spring, autumn and winter, it is not possible to have more than three successive generations during the year. At Pasni the total time taken for the four successive broods was about 14 months. At the utmost, one might have seven generations in the course of two years.

3. At Pasni, there is usually only one brood in the year in the spring months, and as summer is a period of drought, there is no breeding then. On the other hand, Ambagh and Chachro fall within the zone of summer rainfall and breeding occurs only in summer, and there is no breeding in winter and spring, which are periods of drought. Usually, locusts tend to leave areas of drought and migrate elsewhere. However, whenever there is good rainfall in summer at Pasni breeding may take

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place there. Moreover, in years of heavy rainfall young hoppers were being met with at Pasni in certain special areas from June to September, although none were noticed on the general *rek*, (sand dune) areas after May. On investigation, this was found to be due to egg-laying in wet patches of sand laid bare by the heavy south-west wind. This would indicate that breeding may, under these special conditions, continue in these areas in spite of the absence of rainfall. Similarly at Ambagh, light breeding was noted in spring in 1939 as a result of exceptionally heavy rainfall, though usually no breeding occurs there in spring.

4. Although there is usually little possibility of there being more than a single generation at places like Pasni and Ambagh in an ordinary year, the powers of migration possessed by locusts enable them to reach places where they may be able to lay eggs immediately. New adults emerging in April on the coastal *reks* may reach the interior valleys of Mekran and start a new brood in May, and adults of this new generation appearing by the end of June, may migrate to the Rajputana desert in July and may lay eggs during the month. Adults of this generation appearing in September may, under favourable circumstances, start a new brood by the end of the month. Theoretically, therefore, there is the possibility of four successive generations following one another in the course of the year, though ordinarily not more than three broods can be expected.

The length of the incubation period under semi-natural conditions correlated with soil temperature

Eggs are deposited in fairly soft sandy or loamy soils, generally at a depth of about 4 in., and their development is dependent on the existence of optimum conditions of soil-moisture and soil temperature at that depth. Under natural conditions in the desert, the requisite moisture conditions are obtainable only for 3 to 4 weeks after good rainfall, and usually the locust lays its eggs only when the soil-moisture conditions are satisfactory. On the other hand, conditions of soil temperature are affected not only by the diurnal and seasonal fluctuations of atmospheric temperatures, but also by the intensity of solar radiation.

In the course of breeding experiments undertaken at Pasni, the actual times of egg-laying and hatching were noted in a large number of cases and correlated with the average mean temperature of moist sandy soil at 4 in. depth observed in cages during the development. Although the correlations cannot be claimed to be accurate, the results (Table I) may give an approximate idea of the length of the incubation period that may be expected under particular types of seasonal conditions in nature.

TABLE I

Incubation period in relation to soil temperature at 4 in. depth, showing the difference in values for each rise of a degree Centigrade. Compiled from data for the years 1932 to 1937

No. of records	Soil temperature of moist sand at 4 in. depth °C.	Incubation period in days	
		Individual records	Averages
2	19	73, 70	71·5
1	20	48	48
1	21	37	37
6	22	37, 36, 34, 36, 32, 29	34
3	23	28, 29, 29·5	28·8
7	24	27, 27, 26, 29·5, 27, 25, 27	26·9
3	25	25, 24, 25	24·7
11	26	25, 25, 24, 22, 26, 26, 25, 22, 23, 28, 25	24·6
19	27	23, 20, 21, 23, 21, 20, 23, 25, 22, 23, 24, 24, 21, 24, 20, 21, 20, 20, 20	21·8
9	28	18, 19, 22, 22, 19, 19, 19, 18, 19	19·4
11	29	20, 19, 19, 16, 17, 18, 17, 18, 19, 18, 19	18·2
12	30	16·5, 14·5, 14, 17, 17, 17, 17, 16, 17, 17, 17, 16	16·3
24	31	16, 15·5, 15, 14, 16, 16, 13, 16, 15, 18, 15, 16, 16, 17, 16, 14, 17, 16, 14, 15, 14, 15, 14, 15	15·4
13	32	15, 15, 15, 16, 13, 15, 15, 14, 15, 15, 15, 14, 14	14·7
14	33	16, 15, 14, 14, 16, 14, 14, 12, 14, 15, 15, 14, 14, 15	14·4
1	34	13	13

The length of the post-embryonic period under semi-natural conditions, correlated with average atmospheric temperatures

Table II shows the correlation between the average daily mean temperature and the length of the hopper period.

The results show that the shortest period recorded is 32 days at an average mean of 31°C., while at an average of 20°C., the duration is as high as 85 days.

Food and sexual maturation

Bodenheimer [1932] made the suggestion that fresh succulent vegetation growing after rainfall may exert a powerful influence in quickening the sex maturation of locusts. In order to test this, Dr K. R. Karandikar confined pairs of locusts of known age in oviposition cages and fed them on fresh shoots of marrand (*Heliotropium undulatum*). Although the sand at the bottom of the cages had been kept quite dry, the locusts attained maturity in about two months and dropped their eggs on

the surface of dry sand. At that season, there was no fresh marrand anywhere on the Pasni *reks* on account of the drought nor were any mature locusts met with in the area.

TABLE II

The correlation between the length of the post embryonic period and mean atmospheric temperature. Compiled from data of 1933-35

Temperature °C	Minimum duration of post-embryonic development (in days)			
	1933	1934	1935	Averages
20°	...	85	...	85
21°	83	...	...	83
22°	...	...	...	...
23°	...	54	...	54
24°	44	54	...	49
25°	41, 40	...	43, 42, 39, 37	40
26°	35, 36	...	36	36
27°	34, 36	39	...	36
28°	...	...	37	37
29°	...	...	38	38
30°	34	36, 34, 34	...	34
31°	32	...	...	32

TABLE III

Effects of food on sexual maturation

Plant	Yellowing of wings in days	First oviposition in days	Number of egg-pods
Eliotropium undulatum, fresh	13—25	33—79	2—4·4
Ditto, old	17—25	43—90	0—3
Jowari (Sorghum)	13—36	28—72	2—5
Ditto, seedlings	7—20	25—37	3—5·3
Maize	13—16	34—64	1·7—3·7
Sericostoma pauciflorum, fresh	12—25	33—76	1—4
Ditto, old	13—16	39—67	1—3
Aerua tomentosa	15—41	37—104	0—4
Cyperus arenarius	21—68	38—100	0—2
Mixed plants	21	57	1·8
Cabbage	8	24	6
Indigofera cordifolia	17	37	1
Tribulus terrestris	11	36	2

On the basis of these results, further experiments were undertaken. These experiments included (1) the use of fresh shoots of marrand as against shoots of old or semi-dry marrand, (2) old marrand shoots wetted to counter-balance the deficiency of water-content, (3) old marrand kept in a moist atmosphere, and (4) fresh shoots of other food-plants. Subsequent experiments were restricted to comparative tests of fresh and old marrand, of fresh and old kharzan (*Sericostoma pauciflorum*) and to tests of other important food-plants. In all these experiments, the appearance of the yellow tinge of the hind wings has been taken as the first landmark in sex maturation, though the final criterion, of course, would be the date of first oviposition.

The results given in Table III are averages, and the differences do not, for that reason, appear in many cases to be very striking, but they are markedly significant, e.g. in the case of short duration of sex maturation on sorghum, maize and cabbage.

The circumstance that cereal crops like sorghum and maize have been found to hasten the sex maturation of adult locusts is of significance owing to the fact that in all known cases of outbreak centres found in the various parts of Mekran and Lasbela, sorghum crops are associated with their formation. Not only have the hoppers been found on and among such crops, but adult locusts have been observed concentrating in them for feeding and resting. Similarly, in the Sind-Rajputana desert areas, where *bajri* (*Pennisetum typhoideum*) is the chief cereal crop, hoppers as well as adult locusts have been found congregating among the crops. In the absence of cultivation, wild plants like marrand, kharzan, *Indigofera cordifolia* and *Tribulus*, all of which are preferred food-plants, proved by these experiments to have a stimulating effect on the maturation of the locust, may similarly induce outbreak centres to form in those places where they occur in masses.

Food and the rapidity of growth of hoppers

Freshly hatched hoppers were reared individually and in batches on different wild and cultivated food-plants.

The results showed that the food-plants experimented with may be placed in the following order in regard to their effect on the developmental period of hoppers during the hotter months :

Kolhrabi cabbage (31 days) ; sorghum seedlings (35·9) ; *Indigofera cordifolia* (36) ; *Tribulus terrestris* (37) ; *Convolvulus pleuricollis* (38·7) ; fresh *Heliotropium undulatum* (40) ; fresh *Sericostoma pauciflorum* (40) ; maize seedlings (44) ; *Crotalaria burhia* (44·5) ; *Aerua javanica* (45·6).

General observations on food and development

Although the experiments carried out were not exhaustive, they have given fairly definite indications as to the importance of the quality of food in causing an acceleration of the sexual maturation of young adults and of the growth of the hoppers

Since it is now generally conceded that the development of an outbreak centre is almost always due to the rapid development of two generations in quick succession, any factor that might contribute to the speeding up of the breeding would be of the utmost importance in this connection, and there is little doubt that the presence of food-plants capable of stimulating the rapid growth of hoppers and of hastening the maturity of young adults would play an important part in the causation of incipient swarming.

Kennedy [1939] was not inclined to allocate to the food factor anything but a subsidiary role. While conceding that growth-stimulating foods such as *Heliotropium undulatum* might accelerate 'Real Concentration', since the more mobile later instars would thereby be reached sooner, and also that growth stimulation might assist in 'Virtual Concentration' as a result of rapid breeding, he believed that this would only contribute to the fitting in of a second generation into a winter season. He further said (p. 444) that the effect of food on the rate of sexual maturation can only influence prospects of a second winter generation and hence of 'Virtual Concentration', but would have no influence on concentration of the first winter generation.

In the Mekran area of the Indian region, where spring breeding usually occurs, locusts are found over-wintering in the coastal areas and the earliest breeding also occurs there. As the spring advances, locusts migrate into the interior valleys of Mekran from the coast and may breed there if conditions are favourable during the months of April, May and June. Adults of the new generation begin to appear on the coastal areas early in April and usually migrate into the hinterland more or less immediately. As the interior of Mekran is mostly hilly and stony and patches of natural vegetation as well as of cultivation are restricted to loamy soils at the bottom of the valleys, migrating locusts usually become concentrated on such patches (Real Concentration). Summer cultivation there is mostly confined to the sorghum crop, and various wild plants, such as species of *Astragalus*, *Trigonella*, *Tephrosia*, *Tribulus*, *Chrozophora* and *Heliotropium*, as well as the Camel-thorn, *Alhagi camelorum*, all of which are plants relished by locust adults and hoppers, are generally commonly found near cultivation. Locusts concentrated on the sorghum crop may be expected to attain sexual maturity very early and to lay eggs in the neighbourhood, and the hoppers on hatching would find a fair amount of growth-stimulating food. As temperatures in the late spring are fairly high, breeding would be rapid and conditions should apparently be quite favourable for the development of incipient swarms. Although no actual observations have been made on this point, several outbreak centres are known to have developed under such conditions in the interior of Mekran.

As to the adults of the over-wintered brood, it is now fairly well established that the locusts found in the winter months in the Mekran coastal areas are mostly migrants from summer brood areas in the Sind-Rajputana desert. On the coastal *reks* the vegetation is generally very much dried up at the end of autumn, but with the setting in of the moist western winds at the end of autumn, most of the perennial vegetation on the *reks*, such as *Heliotropium undulatum* and *Sphaerocoma aucheri* put forth fresh shoots in spite of the absence of rainfall, and tender shoots may be expected to stimulate sexual maturation even before the occurrence of the winter rains. On the other hand, with the commencement of rainfall, various annuals spring up on the *reks* and furnish food capable, of quickening sex maturity among the over-wintered adults, though there is not much likelihood of any concentration being caused under the conditions prevalent at this period on the coastal areas.

In addition to the natural vegetation, young crops, such as wheat, barley and rape, raised in parts of Mekran would also provide food capable of stimulating maturity, in case locusts happen to be present in the neighbourhood.

Effect of sunlight on the coloration of wings

In recently fledged adult locusts, the hind-wings are always hyaline. In cold weather there may be no development of colour for a long time, but in summer a tinge of yellow usually makes its appearance within a week, signifying the onset of sex maturation and the deepening of yellow colour is a positive indication that the insect is mature.

In many specimens of locusts collected from nature, the occurrence of pink or mauve or light blue colour at the base of the wings was often noticed. During the earlier years of the locust survey work the significance of this coloration was not recognized. It was not till the year 1935, when definite proof of the migration of solitaires was first obtained, that the significance of the possession of distinct mauve or pink patches on the wings in connection with migration was first noted. Observations repeated during the summer and autumn migrations of 1936 and 1937 clearly showed that such a pink or mauve tinge in the wings was, decidedly connected with active migration flight being presumably the effect of the action of solar radiation on the wings, while exposed to the sun during flight. With the object of obtaining a confirmation of this conjecture, some experiments were devised.

A cage was set up in which some recently transformed locusts were introduced after having one, or both, elytra removed. The cage was kept in the open, fully exposed to the sun, which was very bright and hot. In the course of a week or two, wings exposed to the sun had in all cases acquired a pink colour, which subsequently gradually deepend into mauve. In the case of specimens, in which only the right elytra had been removed, it was noticed that pink or mauve had appeared even in the left wing, although the colour was less intense.

In other experiments, Mr R. N. Batra removed the right elytron and painted the other elytron black so as to prevent the sun's rays from infiltrating to the wing beneath, and found no trace of pink or mauve developing on them even at the end of a month, though there was colour development as usual on the exposed wing. When he painted both elytra black, the development of mauve or as pink had been completely eliminated. When right forewings removed, with both elytra removed and with both elytra intact, were kept in boxes locusts, with the completely shut off from sunlight neither pink nor mauve made its appearance, though the yellow tinge characteristic of the onset of sex-maturity developed in due course.

These experiments indicate that the appearance of light mauve or pink in wings, even in those cases where the forewings had not been removed, should have been due to the infiltration of sunlight through the fore-wings.

On the whole, the experiments have fairly clearly proved that the development of pink, mauve or light blue at the base of the hind-wings is the result of exposure to sunlight. In nature, there is a great amount of variation in the type of colour, as well as in the depth of the tinge. Pink is common in the gregarious forms, and in 1935 many of the immigrants showed a pink colour not only on the hind-wings but also on their bodies. On the other hand, mauve is very common among the autumn migrants found in the Lasbela and Mekran areas during the months October to December. In some cases there is only a very light pale bluish suffusion at the base of the wing, and in other the mauve is well developed. In certain cases only the veins acquire a dark bluish colour, while there is no colour at the base. All these differences are probably due to the degree to which the wings have been exposed to sunlight during flight. In the summer months it is probable that migration takes place in the evening or early part of the night while in the autumn months and in winter the nights are cold and movements probably occur during midday or early afternoon. In the latter case there are greater chances of exposure to sunlight and at this time, moreover, locusts love to bask in the sun, hence the deep mauve of the wing-bases and also the darker body colour. Since pink is associated to a greater extent with the *gregaria* forms and mauve tinge with the *solitaria* individuals, an investigation into the physiology of these colour developments may throw much light on their relationship with phase.

BIOMETRICAL STUDIES

Biometrical ratios

The ratio E/F (elytron length over hind femur length) was the one almost exclusively adopted for studying the populations found in different areas. In view of the frequent cases where the tips of the elytra were broken, it was necessary to evolve a method of estimating their length. After various tests, the point where the anal (or vannal) area ends on the posterior margin of the elytron was found the most suitable for determining the position of the specimen on the E/F scale, since the length of the elytron up to the tip of the anal area was found to bear a definite relation to the length of the entire fore-wing. It is proposed to call this point the 'Vannal Apex' or 'Vannal Tip,' and the new ratio, which is determined in exactly the same manner as the E/F ratio, the V/F ratio.

Since the E/F and the V/F ratios are both based on the length of femur (F), the relationship between the two ratios is the function of E/V. By numerous measurements it was found that the function varies between $1 \cdot 30$ to $1 \cdot 33$ on the whole, and in the majority of cases it is between $1 \cdot 31$ and $1 \cdot 32$. If the V/F ratio is determined, E/F ratio would probably lie between $V/F \times 1 \cdot 31$ and $V/F \times 1 \cdot 32$.

In the course of making measurements of the various parts of the locust for the determination of the pronotal ratios, it was apparent that the width of the head was a fairly significant point for examination. A comparison of the heads of specimens of the phases *solitaria* and *gregaria* showed that while there were clear differences in width at the genal region of the face, there were none in the region of the compound eyes. Comparing the facial contours of *solitaria* and *gregaria*, a distinct bulge is seen in the cheeks of the latter, whereas the ocular outline is not dissimilar. In the course of biometrical measurements, a new ratio—C/O, showing the relation between the maximum width of the face at the genal region (C) and the maximum width at the ocular region (O), was worked out along with the other ratios (Table IV.)

The general results of a biometrical examination of the mass of collections gathered in the course of locust surveys indicate that the whole material falls into a long series of forms showing a great variation of characters, with extreme *solitaria*

TABLE IV

Biometrical ratios in different phases

Ratio	*solitaria*	*transiens*	*gregaria*
E/F	1·88—2·05	2·06—2·15	2·16—2·34
P/C	1·617—1·430	1·462—1·315	1·387—1·243
M/C	0·888—0·757	0·887—0·722	0·805—0·705
H/C	1·258—1·666	1·224—1·071	1·187—1·040
C/O	1·02—1·08	1·03—1·07	1·17—1·20

and *gregaria* at either end, connected by an infinite gradation of intermediate forms. The Desert Locust, as a species, may be likened to a mass of plastic material, which yields to the moulding action of its environment in varying degrees and in different ways. In the extreme *gregaria*, sharp differences are noticeable from the *solitaria* forms, in various characters such as longer elytra, shorter femora, a bulge in the cheeks, a depression in the crest of the pronotum, a shortening of the prozona and a constriction in the prothorax. In the intermediate forms, changes may be manifested in only one or two of these characters, and the transition from the *solitaria* to the *gregaria* does not occur as a continuous gradation involving all the characters. Variations in the different characters do not appear to be linked together, but occur independently. A locust having a particular E/F ratio need not necessarily be in the same state of development from the point of view of the other ratios, although an extreme *gregaria* or extreme *solitaria*, may exhibit typical development of all the various characters. Since E/F has proved to be the most expressive and significant ratio, changes in the phase characters have been shown in most cases in terms of this ratio in working out the biometrical facies of locust population in preference to the others.

Biometrical facies of locust populations

General observations made in the course of locust surveys carried out during the years 1931-38 have shown that locusts are being continuously affected by changes in the environment. There may occur as the result of local breeding and multiplication not only an increase in numbers, but also a change in the phase of the population, according to the conditions of the breeding. A similar change in the composition of the population may take place in the event of an immigration from outside. In estimating the character of locust populations, careful biometrical examination of sample collections is necessary. If the results indicate a predominantly *solitaria* facies, the inference would be that there is no immediate danger of swarming ; on the other hand, if there should be a fair proportion of *gregaria*, it may be taken as an indication of tendencies for forming concentrations that may lead to incipient swarming if the conditions are favourable.

In comparing different populations, average biometric ratios may be used, but they do not convey any idea of the extent of variation in regard to phase development in the population. In some cases, the extent of variation is of greater significance than the mean ratio. For instance, the presence of a small percentage of individuals with high *gregaria* ratio among an otherwise mainly *solitaria* population is of particular importance, but it would be obscured by merely quoting the average ratio. The phase variation within a population could be best expressed by tabulating the actual number of individuals in gradations of E/F ratios of the value of 0·05 as done by Zolotarevsky [1938]. The frequency distribution of E/F ratios of similar value among the population can also be represented in graphs, as was done by Kennedy [1939]. In both cases the range and the size of variation is clearly indicated.

In the present study, a different method of showing the constitution of field populations has been adopted. On the basis of a biometrical examination, the population is grouped under 3 categories: *solitaria*, *transiens* and *gregaria*, according to the individual E/F ratios, and it is also further grouped according to the number of eye-stripes possessed by the individuals, which may be either 6 or 7 [Ramachandra Rao and Gupta, 1939].

In regard to the phase characters, it has been found from an examination of specimens collected from flying swarms that the great majority possess E/F ratios 2·16-2·34. On the other hand, the great majority of the non-gregarious locusts have E/F ratios below 2·05, usually between 1·88-2·03. Though it is not possible to fix any rigid limit between the phases in nature, an arbitrary division has been made for the purpose of classifying locust populations, under the following 3 categories : (1) *solitaria* 2·05 and below ; (2) *transiens* 2·06 to 2·15 ; and (3) *gregaria* 2·16 and above (Table IV). Murat [1939] in the course of a biometrical examination of *Schistocerca* in the Spanish Sahara, found that *gregaria* ratios ranged from 2·16 to 2·44 in females and from 2·17 to 2·28 in males, while his *solitaria* ratios ranged from 1·95 to 2·04. His results would appear to support our findings.

On the basis of the number of individuals found under (1) the phase groups of *solitaria* (S), *transiens* (T) and *gregaria* (G), and (2) under the eye-stripe groups, percentages are calculated, and the biometrical facies or index of the population is shown as percentage of individuals with different phase and eye-stripe characters in the following formula :—S : T : T G : : (6) : (7). This method

may be claimed to indicate at a glance the state of development of the population at any particular time or place from the view-point of phase, and has, moreover, been useful in identifying populations in different areas and in tracing the movements of non-gregarious locuts. For example, the population found on the Mekran *reks* in January—March 1935 had the index :—76S : 23T : IG : 34(6) : 66(7), whereas in April—May 1935, the index was :—62S : 29T : 9G : : 67(6) : 33(7). On the other hand, the facies of the locust population on the Mekran *reks* after the locust incursion in July was as follows :—24S : 35T : 41G : : 88(6) : 12(7). The decrease of the proportions of *solitaria* ratios and 7-stripes and the increase of *gregaria* and 6-stripes between January and July was striking and suggested an immigration from outside. Similarly, the facies of the immigrant population in the Sind-Rajputana desert in July 1935 was :— 28S : 43T : 29G : : 92(6) : 8(7), which shows its affinities with the incursion population of Mekran. On the other hand, the index of the new brood found in October-November 1935 in the desert was 69S : 30T : IG : 29(6) : 71(7), indicating a reversal to *solitaria* during the monsoon breeding in the desert. The population found in the Lasbela area in December 1935 had the index :—59S : 41T : OG : : 64(6) : 36(7), suggesting an affinity between the desert brood and the au[illegible]s in the Lasbela area.

In working out the biometrical index, it is advisable to have as large a series of specimens as possible. In the course of the present studies, however, it has been found that even with as small a number as 20 or 25, fairly definite indications of the main characters of a population can be obtained.

Studies on the distribution of the solitary phase

Preliminary surveys

In 1930, at the time of the inauguration of the present scheme of Locust Research in India, there was no definite information available as to the source of the periodical infestations to which India has been subject. Although the generally accepted view was that the initial swarms reached India from a western direction, there was no positive evidence to indicate either that they had been derived from outbreak areas situated within Baluchistan, or that they merely formed a link in the chain of breeding areas connecting India with Arabia and Africa.

It was with the aim of detecting the presence of permanent or semi-permanent outbreak areas, if any, within Indian territory, that a special locust survey staff was appointed early in 1931, and stationed in Baluchistan (with Quetta as headquarters) in the first instance, as the province where such breeding grounds were most likely to be found. In the course of the year 1931, the survey staff examined the areas of Chagai, Lasbela, Mekran and Kharan between February and May. In September, a survey party traversed the desert areas of Kharan State. The Mekran and Lasbela coastal areas were revisited in September-October.

In the course of the following year, similar preliminary surveys were carried out in the rest of the desert or semi-desert areas of North-west India, viz. Kachhi, western Sind, Lasbela, eastern Sind, Jhalawan, Kech and Kolwa, Loralai, the Dera Ghazi Khan and Bahawalpore areas of the Punjab, the Thar area of Sind, and various areas of the Rajputana desert. Surveys of Sirohi, Palanpur Radhanpur and Cutch States carried out in the early months of 1933 completed the programme of surveys designed for obtaining a general knowledge of the distribution of the solitary phase locust within Indian limits. During the years 1932-1933, survey work was greatly facilitated by the provision of a one-and-a-half ton Ford motor-van, which was extensively used in carrying out most of the tours mentioned above. In all those places, however, where the motor-van could not be used, as in the interior of sandy deserts, journeys were performed on camels.

These extensive surveys amply served the purpose for which they were planned. The results obtained gave a general idea of the distribution of the *solitaria* locust population in the Indian area. It was, however, obvious that the records made in the course of these surveys had reference only to the conditions prevailing at the time, and that further surveys, repeated at different parts of the year, would be needed before any inferences in regard to their functioning as permanent reservations of the locust could be made. Moreover, in the course of survey work, a fluctuation of locust population was actually found to have occurred in certain instances.

Intensive regional surveys

In the light of the experience thus gathered, it became evident that the type of surveys that were needed at this stage should be such as were calculated to supply information on the exact effect of seasonal changes on the behaviour and activities of the non-gregarious type of locust. Consequently survey tours of the extensive type were given up, and, from June 1933, survey work was restricted to the areas where solitary locusts were observed to be present, such as parts of Mekran, the Lasbela area and various areas of the Indian Desert. Since 1937, owing to the detection of very intensive breeding in Kachhi and in the hill valleys of Baluchistan, these areas were also subjected to regular periodical surveys. The areas of the habitat of the locust were divided into circles

and sub-circles of convenient size, which were placed under the charge of Assistants and Field-men respectively for purposes of survey work. With the experience gained after a year of intensive surveys, a regular round of visits was plotted for each sub-circle and tours were arranged so that every area was visited once a month where possible (or at least once in two or three months, in particularly large or difficult areas), the staff being instructed to note down on the forms provided the number of locust adults or hoppers found, with particulars of the area covered, the condition of the environment and the state of activity of the insects.

By 1938 the survey comprised five circles, each subdivided in 2-5 sub-circles, of which there were 14 altogether.

Intensive local surveys

Though regional surveys of the type mentioned above have been of great value in giving a definite indication of the locust situation in the area concerned in different seasons, they could not give a continuous picture of the happenings at particular places. In the course of survey work, the data collected indicated not only that there was a fluctuation in the density of locust population at particular localities, but also that seasonal movements of the population were probably occurring. In order to obtain definite proof of such a phenomenon, intensive surveys were carried out in the neighbourhood of selected places throughout the year, commencing from 1934.

Such continuous records of locust activities have been obtained at the following stations :

1. Pasni : as a centre for the western *reks*, in the region of winter rainfall (records from 1932).
2. Ambagh : as a centre for the eastern areas of the Mekran coast, subject to summer rainfall (from 1933).
3. Chachro : as a centre for the south-western parts of the Indian Desert (from 1934).
4. Sardarshahr : as a centre for the north-eastern parts of the Desert (from 1934).
5. Nokh : as a centre for the central parts of the Desert (from 1935).

Method of estimating population density

In the earlier years of the present scheme, the number of locusts or hoppers observed or collected was noted down, as well as fairly detailed particulars of the areas examined. In certain cases, the surveyors gave rough estimates of the population density according to their lights, but they were not exactly comparable.

It was not till 1935 that a general formula for working out the population density of locusts under Indian conditions was evolved. This formula has since been in use, with slight modifications, and has, on the whole, proved quite satisfactory.

In the course of the surveys, it has been observed that the solitary phase adults generally rest on the ground in open patches between bushes and in most cases sit basking in the sun. This is generally the case, while the sand surface temperatures range roughly between 80°-100°F. (about 25°-37°C.). When the soil temperature rises above 100°F. (37°C.), the locust either changes its place by flight or crawls into shade, usually under a bush, for shelter from the sun's rays. On the other hand, when the soil surface temperature falls below 80°F. (about 25°C.), the locust is not very active, and sits basking in the sun as long as possible and ultimately retires for the night at the base of a bush. Therefore it is only within the range of 80°-100°F. surface soil temperature that the best results can be obtained in survey work. During summer months, the optimum time would be between 8 A.M. and 11 A.M. and between 4 P.M. and 7 P.M., while in the winter months the best period would be between 10 A.M. and 3 P.M.

When locusts are most active, they are very sensitive to the approach of men and rise up abruptly from the ground or bush and fly out. Curiously enough, they do not seem to mind camels or cattle unless these approach very near to them. When, however, an observer walks along waving a stick right and left very few locusts will remain undetected, within the range of 10 to 12 ft. on either side. A distance of 11 ft. has been fixed rather arbitrarily, as it is convenient for purposes of calculating fractions of a mile. The distance travelled by an observer during a survey can be determined either by his carrying a pedometer, or roughly by other means. Supposing, for example, a man had walked three miles and had found 10 locusts, the area covered by him might be computed in square miles by multiplying 3 miles by 22 ft., i.e. by 22/5280th of a mile ; thus, 10 locusts were found in an area 1/80th of a square mile, and the approximate density would be 800 per square mile. If a survey party of 5 men had been walking at a distance of about 20 to 30 ft. from each other, and had counted 20 locusts in 3 miles, the population density might be worked out by first computing the total area surveyed by all the 5 men, viz. $5 \times 22/5280 \times 3$ sq. miles, or 1/16 square mile, and then calculating the density which would thus be 16×20, or 320 locusts per square mile. The general formula would be as follows :—

$$P = \frac{L}{\dfrac{22}{M \times 5280 \times D}} = \frac{L \times 5280}{M \times 22 \times D},$$

P, being population density ; M, number of observers ; D, distance in miles ; L, number of locusts found.

If surveys are conducted during the optimum periods in respect of locust activity, this formula gives a fairly correct estimate of the population density.

During 1935, when a large incursion of locusts invaded the *reks* of Pasni, long stretches had to be covered in order to estimate the population and much of the survey work had to be done on camel back. As the locusts flew up, they were counted, just as in the case of foot-surveys. But instead of giving a range of 11 ft. on either side, double that figure was adopted in order to give due weight to the larger size of the camel, and the results obtained appeared to tally with those obtained by foot-surveys. During the subsequent years, however, when the locusts were comparatively few in numbers, camel surveys were found to be of little value and were discarded.

Owing to the extent of the area to be covered by the surveys, the scattered distribution of the locusts and the limited staff available for survey work, any precise determination of the density of population for large areas has been found to be beyond the bounds of practicability. Only random examinations have been possible and the surveys carried out can be considered to be only of the nature of 'samplings'. The number of locusts found in particular surveys is ultimately dependent on the peculiarities of their distribution at those times. The results of individual surveys are thus liable to vary a good deal, though carried out in the same region. In order to counteract the effects of individual variation and make the figures comparable, it was found desirable to work out the average of the density of population for the whole area surveyed. For working out the averages, the following method was adopted: The areas, in square miles, calculated for all the individual surveys, irrespective of whether locusts were noticed or not, were added together to get figures of the total extent of the area surveys. Similarly, the total number of locusts observed in the course of all the above surveys was obtained by adding up the individual results, and from these data, the average population density for the whole area was worked out.

The present method does not aim at any high accuracy, but is useful in providing a rough estimate of the density of locust population at different places and at different times, thus supplying a common basis for comparison in regard to the effect of environmental conditions.

Moreover, what is wanted is not an absolute census of locusts at any particular place, but only a rough indication of an increase or decrease of population, due to local multiplication or to immigration from outside. The experience of the last eight years shows that variations in densities up to 10,000 per sq. mile are not of much consequence, as they represent, in general, mere fluctuations of population. On the other hand, any increase of population above that limit, especially if it is spread over a large area, should be taken somewhat seriously, as there is a likelihood, if conditions should be favourable, of the formation of concentrations of locusts in restricted situations, bringing about crowded breeding. In localities where there is a high concentration of hoppers, such as may lead to an incipient outbreak, the density of the hopper population may reach a million per square mile. A further degree of concentration—probably of the order of 20 to 100 millions per square mile, is presumably needed for the actual formation of a swarm.

Analysis of the survey data 1931—1939

The results of the surveys regularly carried out as described above, have been compared with the weather conditions in the respective areas during each year. The sequence of events in the life of the solitary phase locusts throughout a year shows, on the whole, a striking correlation with the seasonal weather changes, and deviations of weather conditions in particular years are reflected in corresponding fluctuations of the locust population in different areas. The normal annual cycle and its variations, observed each year, are briefly described below.

The overwintering of adults

Only scanty information is available with regard to the winters of 1930-31 and 1931-32. In parts of the Rajputana desert and in the Lasbela and Mekran areas considerable overwintering occurred during the winters of 1933-34, 1935-36, 1936-37, and 1937-38; in these years the breeding in the Sind-Rajputana desert during the preceding summer had been fairly heavy and continued late in the season. On the other hand, during the winters of 1932-33, 1934-35, and 1939-40, there were no overwintering adults in the Rajputana desert and very few in the Lasbela and Mekran. In 1932 there was no rainfall in Rajputana after the 15th August, and in 1934 there was none in September, while in 1938 and 1939, the monsoon rains were very poor in most parts of Sind and Rajputana, so that breeding in these four years was restricted and there was practically no late breeding. Thus, the occurrence of large numbers of overwintering adults is dependent on the late breeding in the Rajputana desert areas during the preceding summer. Locusts of the earlier brood appear to leave the desert areas by September and gradually drift westwards to Baluchistan, subsequently passing into Iran. If there is any late breeding, further flights from the desert follow during October and November, and these late

adults overwinter partly in the desert, and partly in Lasbela and Mekran.

Frosts in many parts of Upper Baluchistan, especially at the altitudes above 4,000 ft., occur almost every night during the greater part of December, January and February, and there are records to indicate that swarms suffer a high percentage of mortality in these upland areas during winter, and cases of mortality among the solitary phase locusts during severe spells of cold weather have also been noticed. In winter, locusts seek the base of thick bushes like those of Siniya (*Crotalaria burhia*) during nights but they generally crawl out during daytime to bask in the sun. In the Mekran coastal areas and in the desert, winters are not severe, but sometimes, especially in the northern parts of the desert as in the Bikaner area, frosts occur on several nights during cold waves, and at such times locusts have been found dead at the foot of the bushes. The following observations made of the behaviour of locusts in a cage with wire-gauze sides kept in the open during the winter months at Quetta, however, indicate that locusts can withstand fairly low temperatures. In a cage in which several hopper had been introduced among small bushes in September, a few became adults in October, but owing to the setting in of cold weather rather early by the middle of October and the occurrence of frosts on several nights, the rest of the hoppers did not show any further growth during the winter. They were found hiding either at the base of thick bushes or in crevices between the framework of the cage and the ground during nights, and came out of their hiding places in the morning on sunny days. During the whole day they remained basking in the sun, and fed a little at midday. They did not emerge on cloudy days. The locusts—both hoppers and adults—survived till the beginning of January, so hat they withstood air temperatures of 17°F. (about —8°C.), but with the fall of snow in the second week of January and the subsequent thaw, they were observed to succumb to the wet cold ; the minimum temperature recorded in January was 13°F.

In the course of survey work, observations were made on he overwintering habits of a few grasshoppers. At Quetta, *Acrotylus humbertianus*, Sauss., was found overwintering under grass in a lawn at a depth of about 1½ to 2 in. and to have survived a snowfall of 4 in. in March 1931. *Anacridium aegyptium*, L. was found hiding in a niche in a building at Quetta in February 1931. At Ahmedwall in Chagai (3,000 ft. altitude) several specimens of *Thisoicetrus persa*, Uv., were collected in March 1931, hiding in crevices in stony ground, having survived a fall of snow. At Chachro in the cultivated area of the desert, some thorn fences were dismantled in February 1935 and several grasshoppers—*Cyrtacanthacris tatarica*, L., *Anacridium aegyptium*, L., *Euprepocnemis alacris*, Serv., etc.—were found. The overwintering is probably a fairly common phenomenon among Acrididae in India.

Except during the winter of 1937-38, when hoppers were also found passing the winter in the Thar area in small numbers along with the adults, the Desert Locust would appear to overwinter only in the adult stage.

Spring breeding on the western reks

The extent and intensity of spring breeding on the western *reks* of the Mekran coast would appear to be directly commensurate with the amount of winter rainfall received. Fairly heavy spring breeding was noticed in 1933, 1935 and 1939 as a result of heavy winter-spring rainfall, while during the spring of 1932, 1934 and 1937, there was an absolute absence of breeding in consequence of an almost total failure of winter-spring rainfall. In 1931, 1936 and 1938, winter precipitation occurred all over the coast, but was below the average, and the spring breeding was, accordingly, light to moderate in character.

Late spring breeding in the interior of Mekran

a. Spring migration. Since 1933, regular surveys of the interior of Mekran were carried out throughout the year, and as a rule, very few locusts were noticeable in the interior of Mekran during the winter months. From March onwards, however, increasingly large numbers were usually met with. From the biometrical characters of the population met with in the interior during the period March to May in the years 1935 and 1936, and from the evidence furnished by the presence of green algae [Ramachandra Rao, 1940] on the wings in 1937 and 1938 in similar population, it is fairly obvious that they were derived from the coastal population of Mekran. The occurrence of yellow-winged forms carrying green algae on the wings in Kachhi-Bolan area in 1937 and 1938, and the finding of a yellow-winged male with mature green algae on the wings as far north as Dalbandin on 4th April 1938, are clear indications of the existence of a general migration from the coastal areas of Mekran and Lasbela into the valleys of the interior with the advance of spring. Similar migration of swarms has been noticed in Baluchistan in the spring months during the last swarming cycle. The probable cause of such migration may be that a rise of temperature accompanied by desiccation starts earlier on the coastal plains than in the upland valleys to the north, which by reason both of a higher latitude and a greater altitude offer more suitable ecological conditions for the breeding of the locust till late in the season.

b. Development of outbreak centres. As a result of the occurrence of good showers of rain in spring in the interior of Baluchsitan in 1935, concentrated breeding was noticed in suitable localities between April and June, leading to the development of incipient swarms in the Kech Valley, in the Panjgur area and in south Kharan. In these cases the breeding represented the second spring generation derived from parents produced on the coast.

In 1936, an outbreak centre was found to have developed in the Kilwa area in March-April, but it was formed by the concentration of overwintered individuals of the old generation. Fairly good breeding also occurred in Kulanch at about the same time. In addition, light breeding representing the second generation of spring was noted in June at Nigor-Kan-Daf in the Panjgur area.

In 1937, owing to the failure of rains on the coast, most of the locusts would appear to have migrated into the valleys of Mekran and Upper Baluchistan. An outbreak centre developed at Sheh Lakhra in the Porali valley of Lasbela in the spring months. Heavy breeding occurred on the Kachhi Plain, and in the Bolan valley in April, May and June, and there is little doubt that the infestation had been started by locusts derived from the Lasbela and Sind-Rajputana areas, where overwintering had been noticed. There was, moreover, a fair amount of breeding in the valleys of the Panjgur area, especially in the Gar-Parom section in June and July, representing the second generation of the season.

In 1938 there was little breeding in the interior in view of the defective rainfall, except in the Kulanch area.

In 1939 heavy winter rainfall occurred both on the coast and in the interior of Mekran, and good breeding was noticed in the Kulanch, Kech and Kolwa areas between March and June, and there is reason to believe that the breeding in these areas might have taken the complexion of outbreak centres if the initial locust population on the coastal areas of Mekran in the winter of 1938-39 had been greater. Heavy breeding would appear to have occurred in the Kachhi-Bolan areas also in the spring of 1939.

In 1926, the year of the commencement of the last great cycle, very heavy rainfall occurred in January, both on the coast and interior of Mekran, and led to heavy breeding on the coast. Subsequently, there was good rainfall in the interior in March and later on in May, which presumably induced widespread formation of outbreak centres in Kulanch in May, and there is reason to believe that incipient swarms developed at the same time also in the Kech and Kolwa valleys.

Movements in summer

The climate of the western parts of Baluchistan resembles that of the regions further west, such as Iran, Iraq and Arabia. It is of the Mediterranean type with rainfall mostly in winter and spring, and with pronounced summer drought. Rains practically cease in March or April, and by the end of April or the beginning of May there is a distinct rise of temperature accompanied by a fall of humidity. In years when there is a failure of winter rain, conditions of desiccation may set in as early as the middle of April, whereas in years of more than average rainfall, this occurs by the middle or end of May. These climatic changes generally take place more or less gradually with the advance of the season, but abrupt rises also occur fairly frequently, either as the result of a heat wave or in the wake of one of the western distrubances. High temperatures are generally accompanied by dry hot winds (*gorich*) from the north or north-west, and may persist for a week or ten days, after which milder weather may prevail till another heat wave sets in. In the Mekran area south-west winds from the coast generally prevail in the afternoons during these intervals.

With a general rise of atmospheric maximum temperatures to over 100°F. (the soil surface temperatures being naturally much higher), and a corresponding fall of humidity, locusts would seem to feel an urge to leave the area, and while the south-west winds prevail, move up through the valleys of southern Baluchistan into Kachhi and west Sind, and thence into south-west Punjab and Rajputana. On the other hand, when the north-west winds are active, locusts find their way into the coastal areas from the interior. Ultimately, however, even those reaching the coast gravitate into the desert areas via Lasbela and Sind. The following examples illustrate the variations in summer movements in various years.

In 1932 a definite incursion of locusts—mostly of the *gregaria* type—occurred on the 24th May on the Mekran *reks*, and was associated with the prevalence of dust storms from the north that had developed during the heat wave of 22nd and 23rd May in Upper Baluchistan. In July 1935, a similar incursion of locusts, but of much greater magnitude, likewise connected with the development of conditions of high saturation deficiency in the interior, was experienced in the coastal areas of Mekran and Lasbela, and in the Thar area of Sind, during the second week of the month. Similar but much lighter incursions were noted in the Pasni area in May 1936, in June 1937 and June 1938, and in all cases a sudden rise of temperature in the interior was found to be involved.

In the Sind-Rajputana desert region, regular observations were begun only from June 1933,

and during the period 1933 to 1939 few locusts were noticed during the winters, none being observable by April. Specimens of a recently developed generation were always found appearing in May or June in most parts of the Sind-Rajputana desert, and as these could not have developed locally it is fairly evident that they represented migrants from the western areas of winter-spring breeding.

With the development of high temperatures in the western areas, locusts would appear to quit them in May-June and to migrate with the south-westerly winds generally prevalent at this period (except during a hot wave) towards the north-east or east into Sind, S. W. Punjab and Rajputana. As a rule, most of the early migrants reach the northern parts of the desert, the migration being directed to the southern parts only when north-westerly winds prevail as a result of an abnormal rise of temperatures in Baluchistan.

In the case of the Thar-Malliani area, locusts may arrive there directly from the western areas, but may more often be conveyed there from the north or north-east by winds connected with the passage of a monsoon depression. In 1938 no locusts were observed around Chachro till the 22nd July, when with the fall of heavy rain due to a depression, fairly good numbers were noticed on subsequent days.

In 1937, when heavy spring breeding occurred in the Kachhi and Bolan areas, locust individuals of a new generation began to appear in the Jaisalmer-Bikaner areas as early as the middle of May. As owing to lack of rainfall there was no spring breeding in the Mekran coastal areas nor any extensive multiplication in the Mekran hinterland, there is reason to believe that most of the migrants found in May and June had originated from the Kachhi-Bolan areas or from the Shah Lakhra area in Lasbela. In 1938 there was no breeding in the Kachhi area and but little in Bolan; and few locusts were met with till the end of June in the Jaisalmer-Bikaner areas. In 1939, on the other hand, fairly good breeding occurred in the Kachhi area, and the earliest immigrations of the year—which were found in June in the Jaisalmer-Bikaner area—were presumably derived from the Kachhi area.

As the infestation found in Kachhi-Bolan areas in the spring of 1937 had been derived mostly from the overwintered locusts found in the Jaisalmer-Bikaner areas, there is probably a linkage between the two areas in regard to locust breeding.

Summer breeding

(*a*) *Sind-Rajputana Area*. The migrants begin to appear in the Sind-Rajputana area generally by the end of May or the beginning of June and the immigration may continue up to the middle of August. By the middle of June a fair proportion of the immigrant locusts is sexually mature, and if the monsoon rains commence by the latter half of June, as they did in 1933, 1934 and 1936, oviposition takes place almost immediately. In 1938, an inch of rainfall was recorded at Bermer on the 31st May, and hoppers were noticed there already by the end of June.

July is generally a month of good rainfall, in which egg-laying is in progress throughout the month, and the first hoppers may be expected by the middle of the month. The June-July batch forms the first monsoon brood, the new adults of which usually appear by the middle of August. Should there be good rainfall also in August, the immigrant locusts may be able to lay a second, and sometimes even a third, batch of eggs in some part or other of the desert, so that hoppers of the first generation may be found up to the middle of September and may continue to transform into adults even up to the end of September.

Generally, however, a break of 2 to 5 weeks' duration in the monsoon rainfall occurs either in July, or in July-August, or in August-September. This has the effect of causing the sand-soil moisture to dry up, and sometimes of raising the saturation deficiency of the atmosphere, as a result of which locusts find the conditions unsuitable for further egg-laying and usually leave the area.

When there is sufficient rainfall in August, adults of the new generation appearing at the beginning of August are able to attain sexual maturity by the end of August or the beginning of September, and to lay eggs that result in the second monsoon generation. As the last batches of eggs of the old generation may also be laid at the same time, an overlapping of generations is bound to occur at this period, though by the end of the breeding season the hopper population may be expected to be made up purely of the second generation.

The production of the late brood—which in effect is mostly composed of the second generation of the monsoon period—is a factor of considerable importance in locust epidemiology. The greatest increase in numbers would occur only if one fairly large brood is quickly followed by a second one within the same breeding period. Otherwise, a considerable decrease in numbers is likely to occur if the bulk of the new generation has to undergo the usual seasonal migration and hibernation before it can breed in the spring, in view of the likelihood of numerous casualties due to adverse weather conditions and natural enemies. In 1926, there was fairly heavy and almost continuous rainfall during July, August and September in the desert areas, especially in the southern parts of the desert where heavy rain occurred in September. Consequently fairly extensive breeding in July-

August was followed in September-October by a second generation mostly in the southern desert, where, favoured by the dynamics of depressions (see below), concentrated breeding was brought about, resulting in the formation of large swarms. The latter spread southwards into Cutch and Kathiawar, north-westwards into southern Punjab and westwards into Sind and Baluchistan, and thus initiated the last locust cycle of 1926-1931.

In 1935, on the other hand, good precipitation in July was followed by deficient rainfall and partial drought in August and September, so that the fairly good breeding that commenced in the wake of the incursion of considerable numbers of locusts from the west was interrupted in August, and there was only a feeble development of the second monsoon generation in September-October.

In 1933, when heavy multiplication occurred as a result of heavy rainfall, especially in the northern areas, a few loose swarms had apparently been produced, which were reported from the outskirts of the desert areas near Muttra and in the Bikaner-Bahawalpur areas.

In 1936, a considerable increase of *solitaria* population was noticed in the Jaisalmer-Bikaner areas in November as a result of late breeding induced by heavy rainfall in August, but no concentrated breeding apparently occurred.

From the experience gained during the last few years, it is obvious that August and September are rather critical months in respect of locust breeding in the desert areas, as the extent of multiplication during the particular season is entirely dependent on the character of the precipitation received during this period.

(*b*) *The Baluchistan Areas*. Summer breeding generally occurs in the Lasbela, Kachhi and Mekran areas in which the monsoon extends its influence. Between 1931 and 1939, there was no summer rainfall in the Lasbela and Mekran areas in 1931, 1935 and 1939 and consequently no summer breeding. On the other hand, in 1932, when a depression carried heavy rainfall into the Lasbela area and into the coast and interior of Mekran during July, extensive breeding was observed all over these areas in July-August-September. In 1933, also, heavy rainfall occurred in July in the Lasbela area, but in Mekran the rains were comparatively light in the interior (Kolwa, Kech and Panjgur) and very light along the coast. Heavy breeding was observed in the Lasbela area between August and October, but in Mekran there was only light breeding in the interior, and none on the coast. In other years, varying amount of rainfall was associated in Lasbela with proportionately varying amount of breeding. In Mekran, however, breeding was noticed in some quantity only in 1937 and 1938 in Kolwa and Panjgur in summer.

Flights induced by dust storms or thunder storms

In the course of intensive observations made in the Sind-Rajputana area between 1934 and 1938, it was often noticed that, soon after rainfall, locusts were found present in localities where they had not been seen previously. It was at first supposed that the presence of locusts was due to the active attraction exercised by heavy precipitation, but observations made in the course of survey work made it clear that in most cases they are brought into the area by the storms that usher in the rain. On 23 August, 1937, large groups of solitary locusts—which were sufficiently numerous to be mistaken for a loose swarm—were reported to have been seen flying with the wind over the town of Sardarshahr at dusk just prior to the occurrence of a thunder storm. It is surmised that these locust groups had been derived from the Reni area to the north-east, where large numbers of adults of the new brood were known to have been present, and that the latter had, in view of the unusual drought that had been prevailing at the time, been excited into activity by the cool, moist winds of the oncoming thunder storm and had allowed themselves to be carried by the storm into new areas. A similar case was observed in the Kolwa area in Mekran in July 1937, when a field-man found fairly large numbers of locusts after rain storms, though none had been found prior to rainfall. In a third case, few locusts were seen in the Nokh area during first week of August 1936, but subsequent to the abnormally heavy precipitation during the second week (12th to 16th), large numbers of them were met with in the same area. Apparently they had been carried into the area by the cyclonic movements of the storms accompanying the passage of the depression. Further instances of this kind were noted in July 1938, when the earliest appearance of locusts during the summer synchronized with the first monsoon shower at Chachro as well as at Nokh [Bhatia, 1939].

In this connection, certain observations (as yet unpublished) which had been made by Khan Bahadur M. Afzal Husain, Dr Taskhir Ahmad and others at Lyallpur in August 1931, on the behaviour of caged locusts, are of particular interest. A large number of locusts, captured from swarms, had been confined in a large wire-gauze cage in the open, and it was found on two occasions that the locusts began to fly about in a state of great excitation and dash against the wire-gauze sides some time before the approach of a dust storm. If in nature locusts similarly respond to changes in the atmospheric temperature, humidity and pressure associated with the approach of rain storms, they would rise into the air of their own accord to meet the winds, and thus get conveyed by them to likely areas of rainfall.

Therefore, the occurrence of thunder storms, or the passage of depressions in summer, is of special significance in the development of outbreak centres in the desert areas.

Autumn migration

With the withdrawal of the monsoon current from North-West India during September, the desert becomes an area of drought accompanied by high temperatures. In years of more than average precipitation during August-September, as in 1931 and 1933, the change to conditions of drought is delayed, occurring only by the middle of October. On the other hand, in years in which rainfall in August-September is defective, as in 1932, 1934 and 1935, conditions of drought develop fairly early in September, and in 1937 an unusual drought developed during a long break in the monsoon in August. During the monsoon months, the maximum temperatures in the desert rarely reach 98°F., whereas they may rise as high as 107°F. during periods of drought developing after the monsoon current ceases. The adult locusts of the solitary phase rest and bask on the surface of sandy soil, and as the temperatures on the surface of sand heated by the direct rays of the sun will naturally be high and the percentage of atmospheric moisture in such locations will also be lower than that in the screen, the discomfort caused to the insect would be very great, so that it generally tries to flee from such situations.

Locusts generally leave the Sind-Rajputana desert area in September-October, and as north-easterly or easterly winds are usually prevalent at this period, the bulk of them would appear to fly towards Sind and Baluchistan. In one carefully observed instance in September 1936 at Chachro, a dust storm that appeared from the north-eastern direction in the afternoon carried off most of the locusts in that area. As by the end of the month the population at Ambagh was found to show a sudden rise, it is surmised that a migration in a westerly direction had taken place. Similarly, in September 1937, the greater part of a fairly high locust population found in the neighbourhood of Chachro was noticed to have been swept away by a depression that passed westwards over that area on the 10th September. More usually, however, emigration from an area is gradual and may be spread over a large number of days, while the conditions of drought last. Much of the autumn migration takes place generally during October, but it may extend up to the middle of November.

In general, however, the heat abates by November, and a slight rise of humidity also occurs, so that locusts do not find the same urge to leave the area. When there is late breeding, most of the adults that are produced by the close of October or during November do not show any indications of leaving the area, and the great majority of them apparently pass the winter in the desert areas, though a certain proportion may, and do, migrate in the course of the winter season during the short spells of comparatively hot weather that sometimes develops there.

In the autumn of 1937, periodical observations were made at several points in the semi-desert area stretching between the banks of the Indus and the Hab rivers, in an attempt to get information in regard to the progress of migration. It was found that locusts were noticeable mostly on the sandy beds of various dry water-courses that drain the semi-desert country. It was also observed that, while locusts were met with during October and November, they were not seen in December, indicating the cessation of migration in winter.

From the information available, it looks as if migration takes place in the form of hops, covering about 10 to 20 miles at a time, the migrating locusts alighting wherever they find sand patches covered with light vegetation for purposes of resting and feeding. Presumably it may take about a week or ten days for migrating locusts to cover the distance between the Indus and Hab rivers, though with a strong north-east wind backing them, it may take much less.

Observations made in 1935-38 indicate that autumnal migration probably occurs in a series of waves that are generally concurrent with periods during which the dry north-east winds are prevalent in Sind, Baluchistan and Rajputana. In many cases, each wave of migration could be traced to a certain extent from the Rajputana area to the Lasbela area, and thence to the Ormara and Pasni *reks*.

Very little is known as to the routes by which migrant locusts reach the Mekran *reks* from Rajputana and vice versa, but there is no doubt that migration is probably guided partly by the direction of the prevalent winds and partly by the orientation of the valleys in the mountainous areas of Baluchistan through which they have to pass. It is probable, for instance, that the migrants that reach the Rumra and Pasni areas from Sind pass through the Kolwa valley. In regard to the locust populations found on the various coastal *reks* of Mekran, it was often noticed that a progressive rise of density occurred in the autumn from east to west, and it is possible that a gradual migration along the coast occurs during the autumn, winter and spring months from east to west, and probably extends into the Iranian areas.

The concentrations of locusts that are almost always noticeable on the coastal *reks* of Mekran are probably to be explained as incidents of

seasonal migration. In summer, locusts get into the *reks* from the interior from a northern or north-western direction, and in autumn and winter from a north-eastern direction. On reaching the coast their migratory flights are presumably halted by a sight of the great barrier of the sea, and the attraction exercised by the *reks* with their scrub vegetation would account for their presence in such numbers along the sea-coast. It is possible that a fair number of locust individuals may be carried by strong winds across the Gulf of Oman into Arabia as, e.g., in the winter of 1936-37 there was some indication that a migration of individuals had taken place across the Gulf into the Muscat-Sharjah area.

Spring breeding in the Sind-Rajputana desert areas

Usually the spring rainfall in the desert is not high enough to induce breeding, but in the spring of 1936 light breeding occurred in north Jaisalmer area. In the spring of 1937, fairly heavy rainfall occurred in the Jaisalmer-Bikaner areas, and as a result fairly widespread but light breeding was noted in April in many places in the northern parts of the desert. Adult locusts of the new generation were found in May. In 1935, good rainfall occurred in spring but breeding did not follow on account of the absence of locusts in these areas.

During the period 1934 to 1939, no spring breeding has been noticed in the southern parts of the desert.

PARALLELISM OF THE ANNUAL CYCLE OF ACTIVITIES OF THE *SOLITARIA* AND *GREGARIA* PHASES

In view of the knowledge gained during the last nine years of the life activities of the *solitaria* phase in the Indian area of its habitat, it might be useful to compare it with what is known of its *gregaria* phase during the last locust outbreak of 1926-31. A short summary of the general scheme of swarm movements is given below.

The winter period

Swarms are generally inactive during the winter months, especially during December and January. During the winters of 1928-29 and 1930-31 there was no over-wintering in the Indian area, but in 1926-27, 1927-28, 1929-30 and 1931-32 large numbers of locust swarms were found in the winter season chiefly in the coastal areas of Mekran and Lasbela, parts of the Sind valley, the Kachhi plain, parts of S.W. Punjab, the outskirts of the Indian desert, and the foothills of the Punjab ranges.

Spring breeding and migration

Mekran. With the fall of winter rains, the swarms over-wintering in the coastal areas may become mature and lay eggs in suitable places. At the same time there occurs a migration from the coast into the interior, generally in a north or north-east direction into the Kech and Kolwa valleys and thence into Jhalawan. Other swarms may move into Panjgur, Kharan and Chagai from the southern parts of Iran. From Chagai swarms may move into Sarawan and Quetta-Pishin, or into the Kandahar valley in Afghanistan via Shorawak and Chaman, and thence through the Arghastan valley into the Kurram valley in the N. W. Frontier Province, reaching the latter by May-June.

Kachhi. Swarms wintering in the plains of Kachhi and west Sind enter the mountain valleys of Upper Baluchistan through the gorges of the Mula, the Bolan and the Nara, ultimately finding their way into Sarawan, Sibi, Quetta-Pishin, Loralai and Zhob districts.

Punjab. Swarms become active in spring and may concentrate and breed between February and April, in districts receiving winter rainfall. There was considerable spring breeding in 1927, 1928, 1930, and little or none in 1929 and 1931. There may be some breeding in spring also in the sub-montane areas of the United Provinces, such as Kumaon.

Sind and Rajputana. Breeding rarely occurs in spring.

Baluchistan. Breeding takes place only in places where good rainfall has occurred. It first occurs in the low-lying coastal areas and in the Kech and Kolwa valleys (February to March), after which breeding is observed in the higher valleys, such as Panjgur, Kharan and Chagai (March to May) and lastly in the uplands of Sarawan, Quetta-Pishin and Zhob (May-June).

The adult locusts belonging to the earliest brood produced in the southern valleys may reach the uplands in the interior in April-May and may lay eggs if conditions are suitable.

Summer migration

Pink swarms of the adults of the new generation produced in spring in Mekran and Chagai fly in May in a north-easterly or easterly direction across Jhalawan and Sarawan till they reach west Sind, Kachhi and south-west Punjab in June. The swarms produced in the uplands in June also fly eastwards into the Sind-Punjab area.

The new generation developed in the Punjab in April-May is generally swept eastwards into the United Provinces, Central India and Bihar by the hot winds from the north-west that blow in May-June on the Indo-Gangetic plains.

The main cause of the eastward migration of swarms from Baluchistan would appear to be the development of conditions of high desiccation that set in, in the interior, at the end of spring and the prevalence of strong south-westerly winds, which carry them into Sind and the Punjab.

The pink swarms from the Baluchistan area generally reach the Sind and South-West Punjab areas in June, and gradually fly eastwards into Rajputana, the east Punjab, and the United Provinces during June-July.

Summer breeding

Baluchistan. The greater part of Baluchistan falls within the zone of summer drought and usually very little summer rain is received, but depressions of the monsoon period may carry considerable rainfall at times into the eastern parts of the country, such as Loralai, Sibi, Zhob, Kachhi, Jhalawan and Kolwa, in which case breeding may occur in these areas. In Lasbela, however, summer breeding is the rule, as it is subject to the influence of the monsoon.

Sind-Rajputana. With the fall of rain, the migrant swarms attain maturity, and there is considerable breeding in the sandy desert areas of Sind and Rajputana. In years of extraordinary rainfall, as in 1929, a great deal of multiplication may occur also in the alluvial areas of Sind.

Punjab and United Provinces. With the development of depressions from the Bay of Bengal, the dominant wind-direction in July-August is usually east to west, and consequently most of the swarms that had reached Bihar and Central India in June are swept back to the west and begin to breed in the Punjab and the western parts of the United Provinces.

The adults of the first generation of the monsoon begin to appear in August, and they are ready to fly in September. There is usually a single generation in summer, but if heavy late rainfall is received in August-September the old generation may continue to lay further batches of eggs and, in addition, the new generation may also begin to breed in the desert areas and in parts of the Punjab. These will assume adult condition only by October-November.

Autumn flights

With the withdrawal of the monsoon, north-west India becomes an area of high temperatures and low humidity, and the change in the climatic conditions has the effect of driving the swarms out of the Punjab, Rajputana and United Provinces. On the Indo-Gangetic plains, westerly winds develop in September-October and may convey the swarms eastwards into Bihar, Bengal and Assam. Some of them may also move into East Rajputana and Central India, and thence southwards into Central Provinces and Bombay Presidency. In western Rajputana, some swarms may be carried southwards into the Kathiawar-Gujarat areas, but a great many are also swept westwards into Sind and Baluchistan, regions where after a period of over-wintering they can breed again in the spring following. Of the flights that move east or south few would seem to survive, as they do not meet with conditions favouring further multiplication.

Comparing the cycle of life ativities of phase *gregaria*, as outlined above, with that of phase *solitaria*, one notices a remarkable parallelism in the main scheme of annual events. In fact, there is the same sequence of concurrences : (1) Over-wintering followed by breeding in the winter rain areas, (2) spring migration from the coast into the interior, followed by breeding in the upland valleys, (3) summer migration to regions eastward as a result of the development of conditions of drought in the west, (4) summer breeding in monsoon areas, and (5) autumn migration—in part at least westwards into Baluchistan owing to the autumnal rise of temperatures with the withdrawal of the monsoon current.

The main differences between the two phases would seem to lie in the greater degree of activity of phase *gregaria*. Both *solitaria* and *gregaria* are similarly affected by the same meteorological and ecological factors provoking them to make long distance migrations, but phase *gregaria* owing to its occurrence in swarms is capable, under the influence of mob psychology, of reaching longer distances and covering wider areas. The area of migration of *solitaria* individuals is confined usually to the coast and interior of British and Iranian Mekran on the west, to the Rajputana desert areas on the east, but extends sometimes as far north as Chagai on the Mekran side and up to Spez and along the Bolan valley, and in the Rajputana area may extend into Patiala territory. On the other hand, swarms of *gregaria* may reach as far north as the Himalayas, as far east as Assam and as far south as the Madras Presidency.

A change in the conception on the origin of outbreaks

At the period when the present investigations were commenced, the general view as to how locust infestation cycles recurred was somewhat as follows. With the breakdown of a locust cycle, the swarms would diminish in number and size and ultimately disappear, and simultaneously the area of their distribution would also gradually become narrowed down to the limits of their permanent breeding grounds, where they would be found as scattered individuals of the solitary phase. If favourable weather conditions, such as heavy rainfall, should occur, intensive breeding would be induced and lead to the building up of a large population during one or two successive seasons. Sooner or later, swarms of the gregarious phase would be formed and invasions of large areas of surrounding country would follow.

The observations recorded during our surveys indicated, however, firstly that the population found in the breeding grounds was rarely of a static character and was marked by strong fluctuations in density, which was affected not only by local breeding, but also by an immigration or emigration of individuals. Secondly, *solitaria* individuals have been found to be capable of migrating long distances, so that those bred in winter-rain areas can reach regions of summer rainfall and vice versa, at the change of the seasons and breed there. Thirdly, phase transformation has been found to occur, not in what have been called the permanent breeding grounds, but in certain ecologically peculiar locations—the outbreak centres—often situated far from them.

From the field observations in regard to the habits and behaviour of the solitary phase in the Indian area, the following would appear to be the general sequence of events in regard to the starting of a new cycle of locust infestation in north-west India.

1. Granting that winter rainfall is heavy and early in the western areas of Baluchistan and that a fairly high population of solitary phase locusts is present on the *rek* areas of Mekran, passing the winter in the comparatively warm climate of the coastal plains, a fairly widespread and intensive breeding might be expected to occur on the sandy *rek* areas; the new generation of locusts would begin to appear by the end of March or the beginning of April.

2. By February, with the general rise of temperatures a migration of locusts from the coast into the valleys of the hinterland would begin. By March, most of the old over-wintered locusts would have reached the interior, and in April and May the new generation from coastal *reks* would follow. The interior of Mekran is a hilly area, most of which is either rocky or stony, and soft soils—mostly fine silts or sandy loams, are to be met with only on the bottom of the valleys, on which most of the patches of cultivation are to be found, generally along the banks of streams or water-courses. In some places, small mounds of fine, wind-blown silt are also to be seen, sometimes on the banks of streams and sometimes at the base of hills. Locusts migrating into the interior are, therefore, attracted to the cultivated fields, and as the soft wet soils in such places offer suitable locations for egg-laying, crowded oviposition would occur. The hoppers hatching therefrom would appear to congregate in the cultivation and undergo a transformation of phase there.

3. Such outbreak centres might occur not only in Mekran, but also in Lasbela, Kachhi and the hill-valleys of Upper Baluchistan, such as Bolan.

4. With the development of dry weather in summer, most of the locusts produced in Baluchistan and southern Iran would appear to migrate eastwards into Sind, Rajputana and Punjab, where they begin to appear in May-June. The migration generally continues into July and August, and quite a large body of migrants may become congregated in various parts of the desert area. Breeding would begin in July, in the event of good monsoon rainfall, and the new generation of locusts produced in the desert might be produced by the end of August. Should further heavy rainfall occur in August and September, a second generation would be produced in the desert, and very often the depressions that pass over the desert from east to west would have the result of causing fairly dense concentrations to occur in the south-western or western parts of the desert, and thus bring about the formation of large swarms.

5. With the development of dry weather, in September-October, the swarms produced in the Rajputana desert area would become dispersed, most of them leaving the area westwards into the Sind-Baluchistan areas, where they can overwinter and breed in the following spring.

From the above, it is obvious that the real danger points are (1) the formation of outbreak centres in the interior of Baluchistan in late spring and (2) the intensive multiplication in the southern and western parts of the desert in September-October. It is both these areas that will have to be watched for and checked in time if the development of a new cycle of locust infestation is to be prevented.

It should be added that the complex of outbreak centres composed of the winter-rain and the summer-rain areas, connected by migrations of locust population, is probably continued into southern Iran and eastern Arabia.

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ABSTRACT

A RÉSUMÉ OF THE SOIL WORK CARRIED OUT UNDER THE CENTRAL PROVINCES RICE RESEARCH SCHEME

(*Report on the soil work carried out under the Central Provinces Rice Research Scheme, Raipur, Government Printing, C. P. and Berar, Nagpur, 1942, Price Rs. 1-8*)

The total cultivated area in the Central Provinces and Berar amounts to 2,49,13,000 acres and the percentage of the area under important crops is, rice 21, cotton 20, *jowar* 17 and wheat 16. It will thus be seen that from the point of view of area, rice is the most important crop of the province and particularly that of the Chhattisgarh Division. Rice is grown on a variety of soils possessing widely varying characteristics in respect of their mechanical and chemical composition. Certain varieties of paddy have been reported to give different yields on varying classes of soils, and their requirement in respect of water for normal growth on different classes of soils is not a constant factor. These and other cognate problems could not be intensively studied by the Department in the past due to inadequate staff and resources. It was therefore proposed to investigate these problems with the help of the Imperial Council of Agricultural Research and the Rice Research Scheme at Raipur was approved by that body for this purpose. The work under this scheme started in September 1932 and was carried out on 2 lines, (1) botanical work consisting of selection of better varieties of paddy and evolution of purple hybrids to enable eradication of karga weed (which is very similar in appearance to the paddy plant) which is found to grow extensively in rice fields, (2) biochemical work involving a growth of paddy, standardization of analytical methods and other cognate problems. Some of the investigations under this head although academic in nature were considered to be necessary in order to obtain the required information in respect of rice soils of the Province.

The report under reference gives an account of biochemical investigations carried out according to the approved technical programme of work and the results obtained are briefly summarized below.

A preliminary survey

(*i*) In the beginning a survey of the rice soils from the various rice growing tracts of the Province was undertaken. Samples of soils to a depth of 18 in. were collected and their mechanical composition was determined and correlated with the yields of paddy. Results obtained showed the following :

(*a*) Under normal conditions fairly satisfactory yields of fine and medium quality rices are generally possible only from such soils whose clay content is 30—36 per cent at a depth of 6-12 in.

(*b*) Soils in which the percentage of clay at 6-12 in. and 12-18 in. depths exceeds 36 and 45 respectively, are usually incapable of giving satisfactory outturns with fine and medium varieties although for many of the coarser types of paddy they might be considered reasonably fit.

Results of chemical analysis have furnished the following important information from a practical point of view :

(*c*) It was found that in general the more the lime content of the soil in a particular tract the less was the yield of paddy.

(*d*) Crop growth has been found to be affected by the degree of acidity or alkalinity (i.e. the nature of soil reaction) present in the soil. Some crops are susceptible even to moderate changes in the reaction of the soil while others are comparatively more tolerant. In the case of the rice crop it was found that optimum outturns could be obtained if the reaction of the soil is either slightly acidic, or neutral, i.e. neither acidic nor alkaline. From the knowledge of the reaction of a particular soil we can thus adopt suitable methods of cultivation and manuring so as to increase or decrease either acidity or alkalinity to the desired extent.

In addition to the above findings, analytical data of fundamental importance relating to the important rice soils have been collected which will be very useful in deciding the nature of treatment to be accorded to a particular type of soil from a specific locality.

(*ii*) Attention was next directed to the intensive study of typical soils of the Chhattisgarh tract and for this purpose samples of soils were taken from the Bilaspur and Raipur districts. These samples were taken to a depth of 4·5 ft. and represented both cultivated and uncultivated soils. Results obtained showed the following important characteristics of the types of soils examined :

(*a*) Light soils (*matasi*). These soils are very poor in lime throughout the profile, i.e. to a depth of 4·5 ft. and contain a low proportion of clay and a high proportion of fine sand, the former generally increasing and the latter decreasing with the depth of the soil. These soils are usually slightly acidic in character.

(*b*) Medium soils (*dorsa I*). These soils contain a high proportion of clay and a low proportion of fine sand, and show a slightly alkaline reaction throughout the profile.

(*c*) Heavy soils (*kanhar*). These soils are similar to the somewhat heavy type of soils designated as *dorsa I* described above.

It will thus be seen that the data which have now been collectd regarding the lime content, reaction, phosphoric acid content and mechanical composition of the various types of soils will be very helpful in distributing proper types of coarse, medium and fine rices to suit specific soils, and suggesting manurial treatments and other methods of soil amelioration with due regard to the lime status and reaction of the soils in question.

Losses of valuable plant food material

In view of the fact that the action of rain and irrigation in removing various plant foods from the soil is intimately connected with plant growth an investigation into the losses of valuable plant food through leaching from different types of rice soils in the Chhattisgarh Division was carried out. Results obtained showed that as the period of leaching increases, there is a progressive increase in the amount of plant food lost from the soil, and that the loss of plant food from light soils is greater than that from heavy soils. These finds therefore suggest the necessity of applying at a time to light *matasi* soils, only small quantities of manures and fertilizers, and judicious use of irrigation water, so as to prevent their loss by leaching, and to maintain the natural soil fertility as far as possible.

Influence of fertilizers

Evolution of carbon dioxide under laboratory conditions from aerobic and water-logged cultures of the two main rice soils, e.g. *matasi* and *dorsa* receiving various manurial treatments was recorded daily for about a fortnight. The manures employed were, cattle-dung, *karanj* cake, ammonium sulphate, superphosphate, both singly and in combination. The main object of this work was to use the production of carbon dioxide as an index of soil fertility. Results obtained show the following :

(*a*) Most of the manures tend to be more ueful in *matasi* than in *dorsa* soil.

(*b*) For *dorsa* soil the treatments that are likely to be most effective are cattle-dung and *karanj* cake.

(*c*) The relative merits of the treatments—ammonium sulphate, superphosphate, and super plus cattle-dung—both under aerobic and water-logged conditions for *matasi* and *dorsa* soils appear to be almost identical.

Dispersion methods for the mechanical analysis of the rice soils

Twenty-one soils collected from various parts of the rice growing tracts of the Central Provinces were analysed by the International and Puri's dispersion methods and their results were compared. It was found that the former method gives a greater amount of clay and fine silt than the latter. The heavier soils were found to give a higher clay percentage with the Puri's method. The soils selected for the experiment had *p*H values varying from 5·4 to 7·6, organic carbon from 0·3 to 1·81, and calcium from 9 to 13·4 per cent. None of these could be correlated with the varying percentages of clay obtained in different soils by the two different methods.

Locally prepared bone-manure and superphosphate

Manurial experiments conducted by the Department have shown that rice responds very favourably to applications of phosphatic fertilizers and that the response is of the highest order when phosphates are used in conjunction with nitrogenous manures. The most important raw-material, namely bones, which contain a high percentage of phosphorus together with organic nitrogen in addition, though available in large quantities are at present not being utilized by the cultivators for manurial purposes. Experiments were therefore conducted to find out cheap and simple method of converting bones into a useful phosphatic manure. It was found that by the 'Alkali method' which is somewhat complicated and by the very simple and cheap method of 'Half charring' which can be practised by every individual cultivator under village conditions, a cheap phosphatic fertilizer can be prepared from bones in the villages.

The effect of the locally prepared bone-manure on the yield of paddy was studied by pot culture experiments, superphosphate being used for the sake of comparison. It was found that the crop responds markedly to the addition of phosphoric acid in the form of either bone-manure or superphosphate.

The economic application of P_2O_5 for paddy has been found to be 20 lb. P_2O_5 per acre. The comparative cost of 1 lb. of phosphoric acid from the bone-manure and superphosphate is found to be as. 0-2-0 and as. 0-9-6 respectively.

Preparation of compost

In order to derive full benefit from irrigation, improved varieties and the like, the soil must contain adequate quantities of organic matter. The usual available method for either increasing or maintaining the organic matter content of the soil is the proper utilization of animal and human excreta. In India a large proportion of the former is however employed as fuel and the latter is very little used as a manure due to caste prejudices and other conservative ideas. Methods are however available by which various vegetable waste materials can be converted into farmyard-like manure which when added to soils will considerably help to maintain their organic matter content. Suitable experiments have therefore been carried out to convert available vegetable waste materials like *karanj* (*Pongamia glabra*) leaves into artificial farmyard manure.

It was found that artificial manure could be successfully prepared from *karanj* leaves and other vegetable materials in shallow pits by adopting rain water method. Composts made according to this method from *karanj* leaves and paddy straw were tried against cattle-dung on the yield of paddy on the two main rice soils of Chhattisgarh. Results which have been statistically examined show that the composts give as good yields of paddy as those given by cattle-dung manure.

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